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How to formulate and solve **optimal stand density over time** roblems for even-aged stands using dynamic programming

Chung M. Chen, Dietmar W. Rose, and Rolfe A. Leary

th Central Forest Experiment Station
est Service, U.S. Department of Agriculture

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HOW TO FORMULATE AND SOLVE "OPTIMAL STAND DENSITY OVER TIME" PROBLEMS FOR EVEN-AGED STANDS USING DYNAMIC PROGRAMMING[1]

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Any intermediate cutting in a forest stand has implications for the growth and yield of the stand following cutting. For example, a severe thinning in a young plantation may significantly reduce the range of possible residual densities as the stand gets older. In general, each cutting decision in a stand affects all future growth, cutting decisions, and returns. Stated another way, forest managers face sequential or interdependent decision-making problems when planning the intermediate harvests in forest stands. An optimal sequence of such interrelated decisions can be derived using the procedure called dynamic programming (DP).

Dynamic programming has been extensively applied in many other areas: inventory and production decisions, allocation and control problems, and in systems design (Bellman 1957, Nemhauser 1966, Wagner 1975). In forestry, however, DP has been used sparingly. Arimizu (1958) used it to regulate intermediate cutting with the objective of producing a maximum harvest volume. Hool (1965), using simply a "cut" or "do not cut" strategy, applied a discrete DP model. Later he introduced a Markov chain approach to production control using a DP model (Hool 1966). Amidon and Akin (1968) compared traditional marginal analysis with DP for determining optimal growing stock and found the latter to be more flexible and convenient. Other authors have illustrated the feasibility of DP for deriving optimal cutting schedules for timber stands (Risvand 1969, Kilkki and Vaisanen 1969, Schreuder 1971).

Unfortunately many of the above papers are difficult to follow because explicit derivation of the solution procedures is lacking. An additional shortcoming of several of the papers is the absence of suitable forest growth models—ones directly related to the decision variable. These two factors, plus the unfamiliarity of most readers with the special conditions which must be met for a problem to be solved as a DP problem, account for the limited application of DP in forestry.

The purpose of this paper is, therefore, not only to derive a set of optimal stand densities over time (an optimum thinning schedule), but also to introduce DP to the reader in a comprehensive, easy-to-understand, way.

CONVERTING TRADITIONAL PROBLEM STATEMENTS INTO THE FORM NEEDED FOR A DP SOLUTION

Traditional Description

A general description of a forest stand may be given in a number of ways: by specifying an individual attribute of the stand, such as its age, species composition, or standing crop. Or, one may give a description by specifying an ordered pair of attributes of the stand (age, standing crop), (standing crop, height), etc. The number and nature of the attributes used to characterize a stand are somewhat arbitrary, but an often-used stand attribute, when just one will suffice, is basal area per acre. We shall refer to basal area per acre as the stand state variable, and associate with it an age variable, although the latter will not be considered a state variable. Other variables that characterize stand attributes of interest are net basal area growth per unit area, basal area harvested per unit area, and some measure of return from the material harvested. Although these variables change in value every year, we will consider their values at periodic intervals. We can summarize the variables used to characterize our forest stand at any particular time, t, as follows:

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[1] *Based on a paper presented by the authors at the Midwest Forest Mensurationists' Meeting at Pingree Park, Colorado, August 14-17, 1978.*

Stand attribute	**Symbol used to designate the attribute**	**Name given to the variable**
standing crop basal area per unit area (pua)	B_{t-1}	state variable
net periodic basal area growth pua	ΔB_t	net growth
basal area harvested pua	Y_t	decision variable
return from basal area harvested	R_t	return

Forest managers frequently want either to maximize physical yield or returns from forest stands. A mathematical statement of this relation for maximum physical yield is:

Maximize (over all harvest cuts) $\sum_{t=1}^{N} \alpha H_{t-1} Y_{t},$

where N = number of the final stage, and

αH_{t-1} = numerical constant times mean height of trees removed at the beginning of stage t.

A statement of this relation for maximum return is:

Maximize (over all harvest cuts) $\sum_{t=1}^{n} R_t$, where R_t is related to Y_t.

Of course, the amount cut at any time t, Y_t, cannot be greater than the amount present at that time, B_{t-1}, nor less than 0.

A geometric portrayal of the above problem statement shows the traditional saw-toothed pattern of stand development following cutting (fig. 1). Maximum physical yield comes from thinning

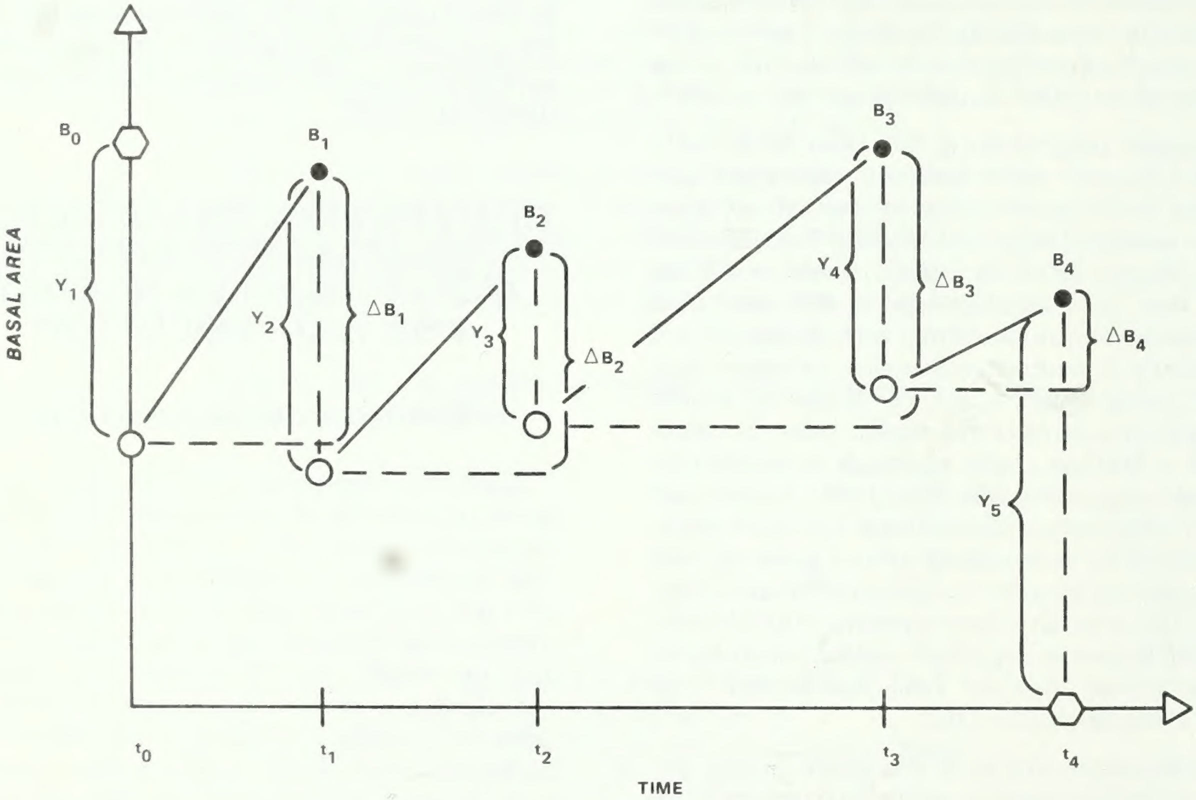


Figure 1. — *Traditional formulation of the "optimal stand density over time" problem expressed in terms of growth periods (t), initial and final stand basal areas (B), and amounts harvested at each cutting (Y).*

intensities Y_t, $t = 1,2,3,4$, in such a way that their sum, plus the final harvest cut, Y_5, is a maximum, or that the return from the four intermediate and one final harvest cut is a maximum.

Let us now convert the familiar problem into a form that lends itself to dynamic programming. To do this we must convert it into a description for a multistage decision problem.

Multistage Decision Process Description

The limited use of DP in forestry has come about not because forestry has no suitable problems, but rather because many potential users have not known how to formulate problems so that DP can be used to solve them. Part of the difficulty may stem from the DP symbolism—the shorthand used in expressing problems in a multistage decision process. Another source of confusion is the variety of decision process frameworks: deterministic, stochastic, finite time, infinite time, discrete state, continuous time, etc. We will treat two types of deterministic, finite time problems in this paper. They are both discrete time, one being discrete state and one continuous state (fig. 2).

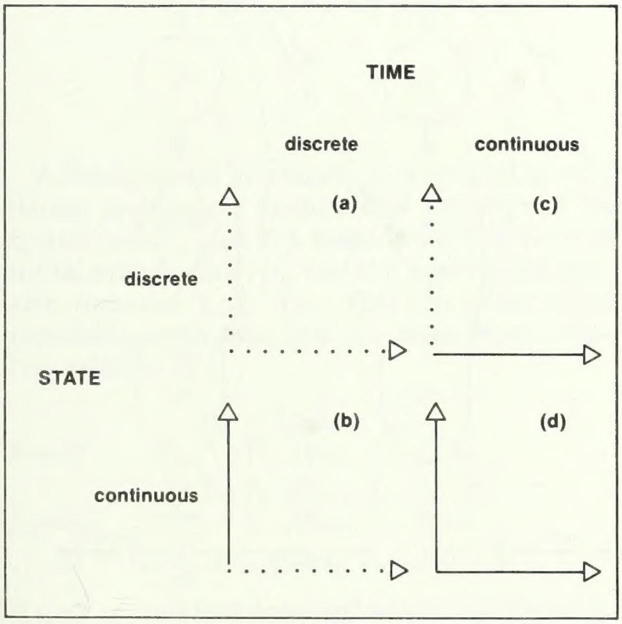


Figure 2. — *Kinds of deterministic multistage decision problems. Problems of type (a) and (b) are treated in this paper.*

Let us return briefly to the symbolism used in expressing multistage decision processes. In addition to the normal "let B designate basal area per unit area" type of symbolism, we have the following:

(1) Small "n" designates one of the discrete times called a stage. "Stage" can also be read as "growth period." Thus, B_n designates basal area at the end of stage (growth period) n.

(2) "(,)" signifies the arguments in a traditional mathematical function. Normally the arguments are related in some arithmetic manner, such as

$y=f(x,z)$, where $f=x+z$ or x/z, etc.

(3) "[,]" signifies a more general situation than "(,)". The arguments in the square brackets can be simple variables, such as x, as well as functional relationships between x and, say, z. Thus, [x,z] may be shorthand for $x+z-f(x,z)$, where $f = x/z$. Normally "[ ]" designates a transformation.

An additional source of confusion in DP stems from using symbols for a functional relation and its numerical value. Normally in mathematics one does not write $y=y(x,z)$, because the y to the left of the equality designates the numerical value of the function on the right side. Normally one would say $y=f(x,z)$, with f designating the manner in which x and z are combined. But in DP problem formulation it is normal to use expressions such as $T=T[x(1),u(1),\ldots,u(N)]$. It is usually safe to associate the letter "T" with the transformation implicit in the brackets, but sometimes "T" stands for the numerical value of the quantity on the righthand side of the equality. In the latter case, it should have a stage number attached—for example, T_n—to indicate over how many stages the transformation applies.

(4) "{ }" is typically used as

$$\max_{u(1)\ldots u(N)} \left\{T[x(1),u(1),\ldots,u(N)]\right\}$$

subject to any
restrictions

to designate "the maximum value of T[x(1), u(1), . . . ,u(N)]that can be obtained by adjusting u(1), . . . ,u(N) without infringing on any of the restrictions".

Now let's convert the traditional expression of the problem into the form required for multistage decision problems. First, we need to identify the old variables in their new garb:

n — instead of the continuous time variable, t, we shall use the discrete variable n to designate a stage in time. Ordinarily, "n" takes on values from 1 to N. The value of N is often used to classify the problem; e.g., if $N=4$, we refer to a four-stage process. In this paper a stage is treated as a growth period of unspecified length.

B_{n-1} — basal area per unit area at the beginning of stage n.

Y_n — the amount of basal area removed per unit area at the beginning of stage n.

ΔB_n — net periodic basal area increment per unit area during stage n.

R_n — the return at the beginning of stage n. It is related to the amount cut, Y_n— i.e., the decision variable.

$(B_{n-1}-Y_n)$ —the residual basal area per unit area at the beginning of growth period n.

The traditional and multistage formulations of the optimum stand density problem are actually very similar. The traditional form was given in figure 1, and the multistage form in figure 3. The time axis in (1) has been divided into stages of uniform length in (3), each with a beginning and an end. The standing crop, $B_0, B_1, \ldots, B_{N-1}$, is reduced at the beginning of each stage by an amount $Y_1, Y_2, \ldots Y_N$ to give residual standing crop at the beginning of each stage, (B_0-Y_1), $(B_1-Y_2), \ldots, (B_{N-1}-Y_N)$. The latter standing crop values form the base on which growth is based during the stage, e.g., ΔB_1 occurs during stage one, begins with (B_0-Y_1), and ends with B_1. Similarly, ΔB_2 occurs during stage two, begins with (B_1-Y_2), and ends with B_2, etc.

With these old ideas in new garb, let us re-express our objective using

$$\max_{Y_1, Y_2, \ldots, Y_N} \sum_{n=1}^{N} R_n$$

$$\text{subject to: } B_n = B_{n-1} - Y_n + \Delta B_n,$$
$$0 \leq Y_n \leq B_{n-1}, \text{ with } B_0 \text{ given, and}$$
$$R_n = R_n(B_{n-1}, Y_n).$$

The objective is to determine how much to thin at stage 1, Y_1, stage 2, $Y_2, \ldots,$ and stage N, Y_N, such

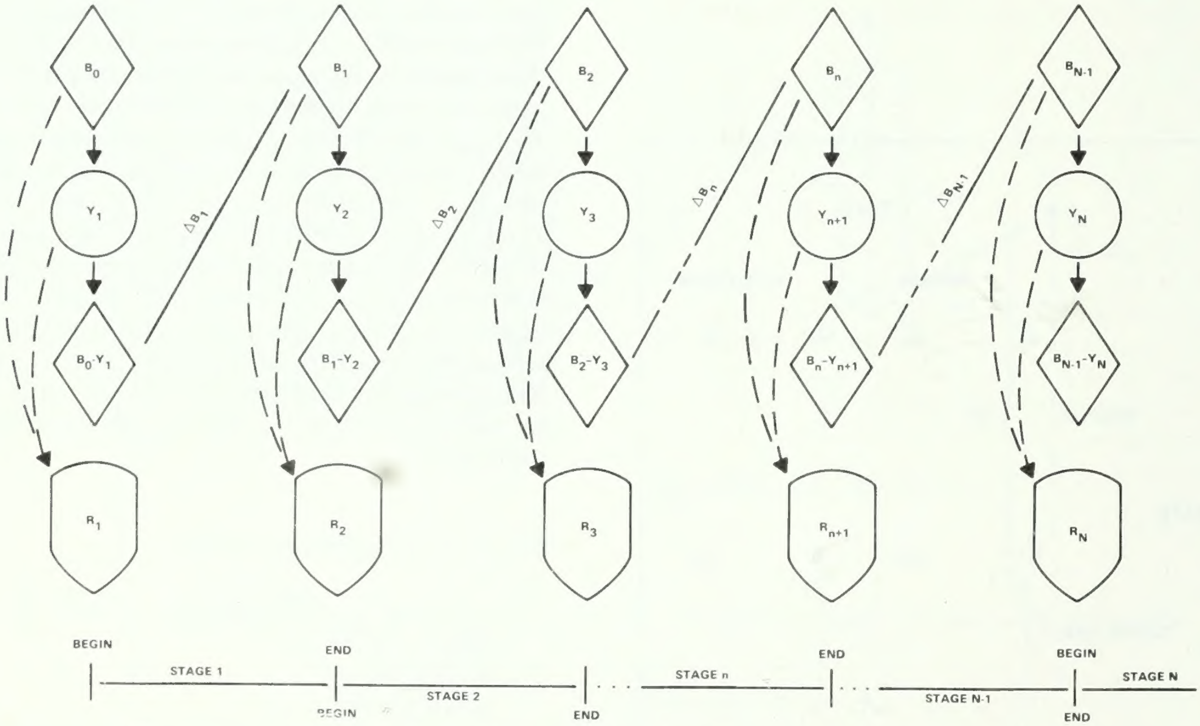


Figure 3. —*Multistage decision problem formulation of the "optimal stand density over time" problem. The decision variable, Y, is contained in the circle. Note the numbering of the stages, and that a point in time may, simultaneously, be the end of stage n-1 and the beginning of stage n.*

that the sum of the returns from the intermediate cuts plus the final clearcut is maximized when the forest standing crop basal area, B_n, changes as indicated.

Looking at the change in more detail we have

$$\left(\begin{array}{c}\text{Basal area}\\ \text{at } \textit{end} \text{ of}\\ \text{stage } \textit{n}\end{array}\right) = \left(\begin{array}{c}\text{Basal area}\\ \text{at } \textit{end} \text{ of}\\ \text{stage } \textit{n-1}\end{array}\right) - \left(\begin{array}{c}\text{Basal area}\\ \text{removed at}\\ \textit{beginning} \text{ of}\\ \text{stage } \textit{n}\end{array}\right) + \left(\begin{array}{c}\text{Net basal area}\\ \text{growth } \textit{during}\\ \text{stage } \textit{n}\end{array}\right), \text{ or}$$

$$B_n = (B_{n-1} - Y_n) + \Delta B_n \qquad (1)$$

Equation (1) is called the recursive relationship for stage dependence.

Looking further at the growth component of (1), we have

$$\Delta B_n = g(B_{n-1} - Y_n, S, \text{age}), \qquad (2)$$

where g is an unspecified (for now) mathematical combination of what is available to grow during stage n, $(B_{n-1} - Y_n)$, site (S), and stand age.

This, of course, is a stand growth formulation as opposed to an individual tree growth formulation. Equation (2) can be simplified by removing age from the argument list and letting the mathematical function itself carry age's proxy, stage:

$$\Delta B_n = g_n(B_{n-1} - Y_n, S) \qquad (3)$$

Substituting equation (3) into (1) gives a more complete statement of the "recursive relationship for stage dependence":

$$\begin{aligned} B_n &= (B_{n-1} - Y_n) + g_n\,(B_{n-1} - Y_n, S) \qquad (4)\\ &= T_n[B_{n-1}, Y_n] \text{ for a given site.}\end{aligned}$$

A fundamental stratagem in formulating multistage problems is to show that the state of the system, our B_{n-1}, at any stage is a function of the initial system state, B_0, and the intervening decision variables $Y_1 \ldots Y_{n-1}$. This can be shown by repeated substitution into the stage transformation relation T[ ],

$$B_n = T_n[B_{n-1}, Y_n].$$

Recall $\quad B_{n-1} = T_{n-1}[B_{n-2}, Y_{n-1}]$, so

$$B_n = T_n\big[T_{n-1}[B_{n-2}, Y_{n-1}], Y_n\big].$$

Again, $\quad B_{n-2} = T_{n-2}[B_{n-3}, Y_{n-2}]$, so

$$B_n = T_n\big[T_{n-1}\big[T_{n-2}[B_{n-3}, Y_{n-2}], Y_{n-1}\big], Y_n\big].$$

If n=3, and we look only at the variables in brackets, we see the only state variable used is B_0 — the initial system state — but all the decision variables are used, i.e.,

$$B_3 = T_3'[B_0, Y_1, Y_2, Y_3]. \qquad (5)$$

This says simply that the basal area at the end of stage 3 is dependent on the basal area present initially, B_0, the amount cut (Y_n, n = 1,2,3), and any relationships between B_n and Y_n that are implicit in the stage transformation T[,]. The "′" on T in equation (5) simply means that the substitution of previous stage transformations has been carried to completion— completion being when B_0 is the only state variable in the list of stage transformation arguments.

A parallel stratagem is employed for the stage return, R_n. Figure 3 shows that the return at the beginning of stage n, R_n, is affected by the decision variable at the beginning of nth stage, Y_n, and the state variable at the end of the previous stage, B_{n-1}, i.e., R_2 is affected by Y_2 and B_1. Thus

$$R_n = R_n(B_{n-1}, Y_n), \qquad (6)$$

and, as before, $\quad B_{n-1} = T_{n-1}[B_{n-2}, Y_{n-1}]$.

Carried to completion we have the "recursive relationship for stage dependence," i.e.,

$$R_n = R_n'(B_0, Y_1, Y_2, Y_3, \ldots, Y_{n-1}, Y_n). \qquad (7)$$

This simply states that the return from managing a forest to the beginning of the nth stage is related to how much has been harvested, Y_n (n=1, . . . , n), how much standing crop was present initially, B_0, and the relationship (invisible in this notation) between growing stock and cut given in

$$B_n = (B_{n-1} - Y_n) + g_n(B_{n-1} - Y_n, S).$$

SOLVING MULTISTAGE DECISION PROBLEMS WITH DP

Up to this point we have concentrated on converting the concepts and terminology used in expressing traditional forest management problems to those used in expressing multistage decision problems (table 1). Now let's solve our problem using DP.

A universal limitation on using DP to solve multistage decision problems is called the decomposability constraint, and it applies to the total return function

$$TR_N = TR(R_1, R_2, \ldots, R_N)$$

Table 1. — *Traditional and multistage decision descriptions of the problem of determining an optimal cutting regime for one rotation of an even-aged stand*

Traditional description	Multistage decision description
Cutting will be spread out over the rotation.	A series of decisions is required.
Standing crop cannot be more than previous standing crop plus growth. Maximum cut is a clearcut.	There are restrictions on the possible values of the state variable B_{n-1} and the decision variable Y_n.
Standing crop in a stand depends on how much was available to grow. Amount cut at any given time depends on amount cut earlier in the rotation.	The state at the end of stage n, B_n, depends on the state at the previous stage and the decision, (Y_n) which depends on previous decisions $Y_{n-1}, Y_{n-2}, \dots, Y_1$.
Cutting opportunities occur at X-year intervals of which there are N.	The process runs for N stages.
Each cutting opportunity results in some (possibly zero) level of cutting.	Each stage of the process requires a decision, Y_n, that can be converted to a return, R_n.
The total return from managing a forest depends on the returns from each cut.	The total return from N stages of the process, TR_N, depends on the returns from each stage according to some functional relationship,i.e., $TR_N = TR(R_N, \dots, R_n, R_{n-1}, \dots, R_1)$.

for an N-stage process. According to Nemhauser (1966), the objective of decomposing the total return function into N equivalent subproblems is to have a formulation where:

1) Each subproblem contains only one state variable B_{n-1} and one decision variable Y_n, $n=1,2,\dots,N$.
2) Each of the subproblems will be roughly equivalent to a one-stage optimization problem, but all the decisions are interdependent.
3) The optimal decision Y_n^* (for $n=1$, $n=2, \dots n=N$) will be derived one at a time.
4) The optimal solutions from the subproblems are combined to derive the optimal solution to the whole problem.
5) The decomposition, according to the principle of DP, insures that the number of feasible solutions does not change from the original number, and the value of the objective function associated with each feasible solution also does not change.

Two mathematical properties of the return function are sufficient for decomposition to be valid: separability and monotonicity. They are discussed in Nemhauser (1966), pages 34 to 39. The simple return functions used in this paper are known to be decomposable.

We now need to develop our return function. The total return (TR_N) from the first stage through the Nth stage is some as-yet-unspecified function of the individual stage returns

$$TR_N = TR(R_N, \dots, R_n, \dots, R_1) \tag{8}$$

$$\text{where} \quad \begin{aligned} R_n &= R_n(B_{n-1}, Y_n) \\ &= R_n'(B_0, Y_1, \dots, Y_n) \\ &\quad \text{for } n=1, \dots, N. \end{aligned}$$

Let us introduce a new variable $f_N(B_0)$ as follows:

$f_N(B_0)$ = the optimal value of TR_N using the optimal cutting policy over N stages (growth periods) starting from the state B_0.

$$= \max_{Y_N, Y_{N-1}, \dots, Y_1} \left\{ TR(R_N, \dots, R_1) \right\} \tag{9}$$

subject to constraints

The problem is to choose Y_n, $(n=1, \dots, N)$ so that equation (9) is true.

A simple and reasonable optimal return function that can be decomposed is

$$f_N(B_0) = \max_{Y_N, Y_{N-1}, \dots, Y_1} \left\{ \sum_{n=1}^{N} R_n \right\} \tag{10}$$

subject to constraints

Recall the return at the beginning of stage n is

$R_n = R_n(B_{n-1}, Y_n)$ and that the stage transformation is

$$B_{n-1} = T_{n-1}[B_{n-2}, Y_{n-1}] = T_{n-1}'[B_0, Y_1, Y_2, \dots, Y_{n-2}, Y_{n-1}]$$

as well as

$$R_n = R_n'(B_0, Y_1, Y_2, \dots, Y_{n-1}, Y_n).$$

So, in expanded terms, equation (10) is:

$$f_N(B_0) = \max_{Y_1, \dots, Y_N} \left\{ \begin{aligned} & R_1(B_0, Y_1) + R_2(B_1, Y_2) \dots \\ & \quad + \dots R_n(B_{n-1}, Y_n) \dots \\ & \quad + \dots R_N(B_{N-1}, Y_N) \end{aligned} \right\}$$

subject to constraints

or

$$f_N(B_0) = \max_{Y_1, \dots, Y_N} \left\{ \begin{aligned} & R_1(B_0, Y_1) + R_2'(B_0, Y_1, Y_2) \dots + \dots \\ & R_n'(B_0, Y_1, \dots, Y_n) \dots + \dots \\ & R_N'(B_0, Y_1, \dots, Y_{N-1}, Y_N) \end{aligned} \right\}.$$

subject to constraints

When the total return function is decomposable, we can modify the above equation as follows and not change its value:

$$f_N(B_0) = \max_{0 \le Y_1 \le B_0} \left\{ R_1 + \max_{Y_2, \ldots, Y_N} \left\{ R_2'(B_0, Y_1, Y_2) \ldots + \ldots R_n'(B_0, Y_1, \ldots, Y_n) \ldots + \ldots R_N'(B_0, Y_1, \ldots, Y_N) \right\} \right\}.$$

Done once legitimately, it may be repeated:

$$f_N(B_0) = \max_{0 \le Y_1 \le B_0} \left\{ R_1 + \max_{0 \le Y_2 \le B_1} \left\{ R_2'(B_0, Y_1, Y_2) + \max_{Y_3, \ldots, Y_N} \left\{ R_3'(B_0, Y_1, Y_2, Y_3) \ldots + \ldots R_N'(B_0, Y_1, Y_2, \ldots, Y_N) \right\} \right\} \right\}.$$

Expressing this in a recursive manner gives

$$f_N(B_0) = \max_{0 \le Y_1 \le B_0} \left\{ R_1 + f_{N-1}(B_1) \right\}, \quad (11)$$

where $R_1 = R_1[B_0, Y_1]$, and $B_1 = T_1[B_0, Y_1]$.

Decomposing $f_{N-1}(B_1)$ in equation (11) further, we have, generally

$$f_{N-(n-1)}(B_{n-1}) = \max_{0 \le Y_n \le B_{n-1}} \left\{ R_n + f_{N-n}(B_n) \right\} \quad (12)$$

for $n = N, N-1, \ldots, 2, 1$, when we use the backward solution approach. Note that equation (12) is identical to equation (11) when $n=1$ — i.e., at the final solution stage. Describing the variables in equation (12), we have

$f_{N-(n-1)}(B_{n-1})$ = the cumulative return over $N-(n-1)$ stages when the backward solution reaches the beginning of the nth stage, with state variable B_{n-1}, having used optimal decision variables $Y_n, Y_{n+1}, \ldots, Y_N$.

R_n = the return at the beginning of nth stage = $R_n(B_{n-1}, Y_n)$, with Y_n the basal area thinned at the beginning of the nth stage, and

$f_{N-n}(B_n)$ = the cumulative return over $N-n$ stages when the backward solution reaches the beginning of the $(n+1)$ stage, with state variable B_n, having used optimal decision variables $Y_{n+1}, Y_{n+2}, \ldots, Y_N$, and

$B_n = T_n[B_{n-1}, Y_n]$.

Figure 4 summarizes how equation (12) works in the backward solution approach.

Equation (12) expresses what is called the functional recurrence relation.

If we have a four-stage decision problem such as the one portrayed traditionally in figure 5a and in the multistage form in 5b, the equation embodying the functional recurrence relation is given in 5c. From 5a we see that we know two states of the system: B_0, the initial state, and B_4 the final state. Since we are clearcutting the stand at the beginning of the Nth stage, $B_N = 0$.

Now let's work the equation in 5c backwards for four stages.

Start: $n=4$

$$f_1(B_3) = \max_{Y_4} \left\{ R_4 + f_0(B_4) \right\}$$

a) From figure 5a we see that $B_4 = 0$, therefore $f_0(B_4) = 0$, and

$$f_1(B_3) = \max_{Y_4^* = B_3} \left\{ R_4 \right\}$$

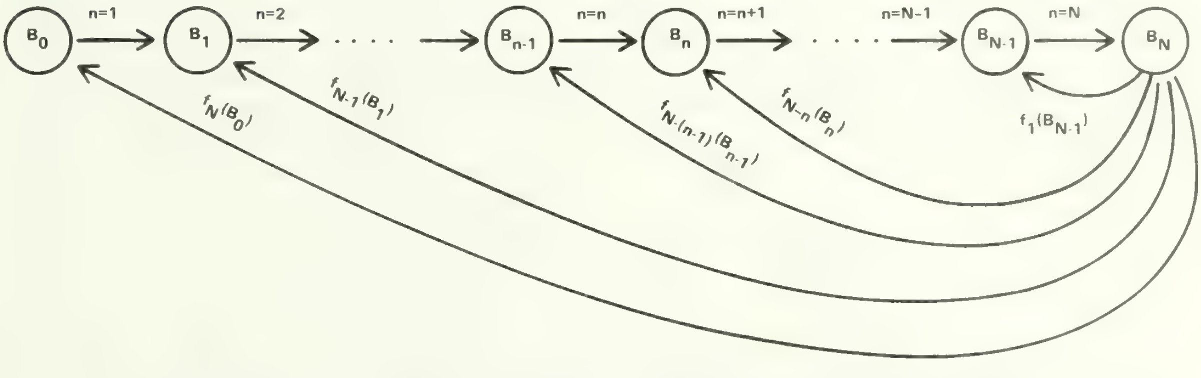
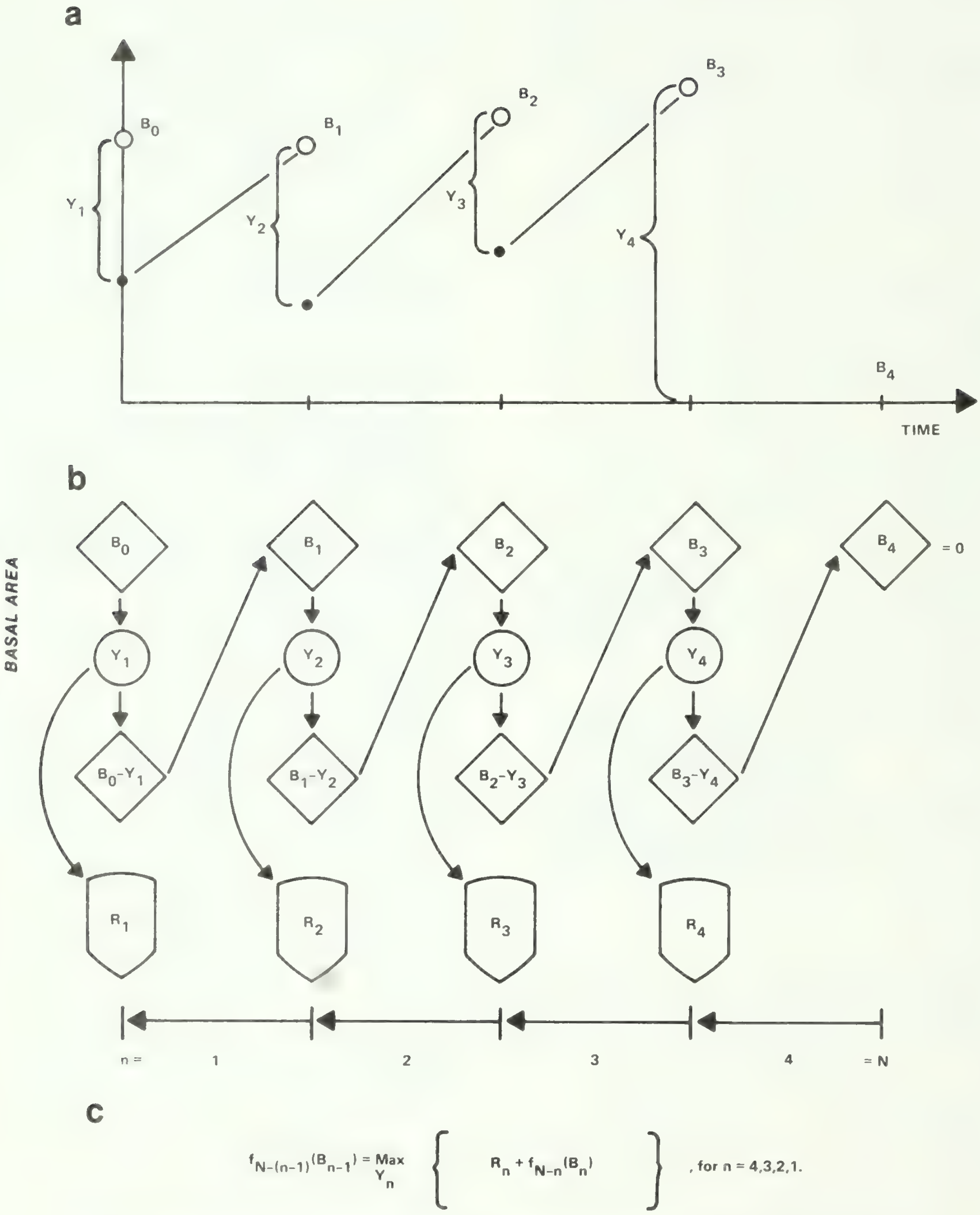


Figure 4. — *Schematic summary of relations given in equation (12).*



$$f_{N-(n-1)}(B_{n-1}) = \underset{Y_n}{\text{Max}} \left\{ R_n + f_{N-n}(B_n) \right\} \text{, for } n = 4,3,2,1.$$

Figure 5. — *Traditional geometric (a), multistage decision (b), and DP formulations (c) of the "optimal stand density over time" problem.*

b) The optimal decision is to clearcut at beginning of stage 4, at which time there is B_3 basal area.

Let n=3

$$f_2(B_2) = \max_{Y_3} \left\{ R_3 + f_1(B_3) \right\},$$

with $f_1(B_3)$ coming from the above equation.

When n=2

$$f_3(B_1) = \max_{Y_2} \left\{ R_2 + f_2(B_2) \right\}, \qquad \text{and}$$

when n=1, the final solution stage,

$$f_4(B_0) = \max_{Y_1} \left\{ R_1 + f_3(B_1) \right\}. \qquad (13)$$

Repeatedly substituting what is known into equation (13) gives

$$f_4(B_0) = \max_{Y_1} \left\{ R_1 + \max_{Y_2} \left\{ R_2 + f_2(B_2) \right\} \right\}, \text{ and}$$

$$f_4(B_0) = \max_{Y_1} \left\{ R_1 + \max_{Y_2} \left\{ R_2 + \max_{Y_3} \left\{ R_3 + f_1(B_3) \right\} \right\} \right\}, \text{ and finally}$$

$$f_4(B_0) = \max_{Y_1} \left\{ R_1 + \max_{Y_2} \left\{ R_2 + \max_{Y_3} \left\{ R_3 + \max_{Y_4} \left\{ R_4 + f_0(B_4) \right\} \right\} \right\} \right\}, \text{ or}$$

$$= \max_{Y_1, Y_2, Y_3, Y_4} \left\{ \sum_{n=1}^{N=4} R_n \right\}.$$

To solve the DP problem above, we need to know the numerical values of two variables: B_0 and $f_0(B_4)$. B_0 is the initial stand basal area and $f_0(B_4)$ is the cumulative return over 0 stages. Because we are clearcutting at the beginning of stage four we know $f_0(B_4) = 0$. This allows us to determine the innermost maximum, and progressively work our way to the outer maximum.

NONCALCULUS SEARCH OF A NETWORK USING DP

Suppose we possess the ability to simulate the development of forest stands with and without thinning. This ability may be based on, say, a stand or individual tree growth projection system. Then, for a species on a given site class, an initial stand density (B_0) branches according to different levels of basal area removed at the beginning of the stage (growth period). The basal area at the end of the first growth period is given by $B_n = B_{n-1} - Y_n + \Delta B_n$, with n=1. The process is repeated for as many values of Y_1 (thinning levels) as we wish to try. Let us say we try three different values of Y_1, giving rise to three values of B_1 at the end of the first growth period. For each of the three resulting values of B_1, there can be several values of Y_2 tested, giving a set of B_2 values at the end of the second growth period. Carried to completion, the result is a network such as that shown in figure 6. This figure shows that from one to three cutting intensities were tried at the beginning of each stage for each state at that stage. Thus, at the beginning of stage three there are four possible states (BA = 185, ^{1}145, 175, and ^{2}145), and each was tested with two thinning intensities. Of course, many more thinning intensities can be tested, but the resultant computational load is best handled by a computer. Since we are dealing with a number of stages and a discrete number of states at each stage, the problem can be classified as discrete stage-discrete state (fig. 2).

To facilitate handling the functional recurrence equation of DP we attempt to find the thinning schedule that will maximize total cords harvested from this hypothetical stand by applying the formulation

$$f_{N-(n-1)}(B_{n-1}) = \max_{Y_n} \left\{ V_n + f_{N-n}(B_n) \right\} \qquad (14)$$

to EACH NODE OF EACH STAGE. (We have substituted V_n for R_n because the objective is maximum physical volume yield.)

Of course, N=4, so

$$\text{for } n=4 \quad f_1(B_3) = \max_{Y_4} \left\{ V_4 + f_0(B_4) \right\}.$$

As before, $f_0(B_4) = 0$, because of the pre-established decision to clearcut at the beginning of stage N(=4). Thus,

$$f_1(B_3) = \max_{Y_4^* = B_3} \left\{ V_4 \right\}$$

This equation applies for every value of B_3, so we list them here along with the cordwood yield that would result from clearcutting the stand with B_3 square feet of basal area:

$f_1(176) = 60$ $\qquad f_1(175) = 75$

$f_1(140) = 55$ $\qquad f_1(148) = 70$

$f_1(160) = 60$ $\qquad f_1(165) = 75$

$f_1(146) = 65$ $\qquad f_1(152) = 70$

Having evaluated equation (14) for every node under B_3 in figure 6 we proceed backward to the

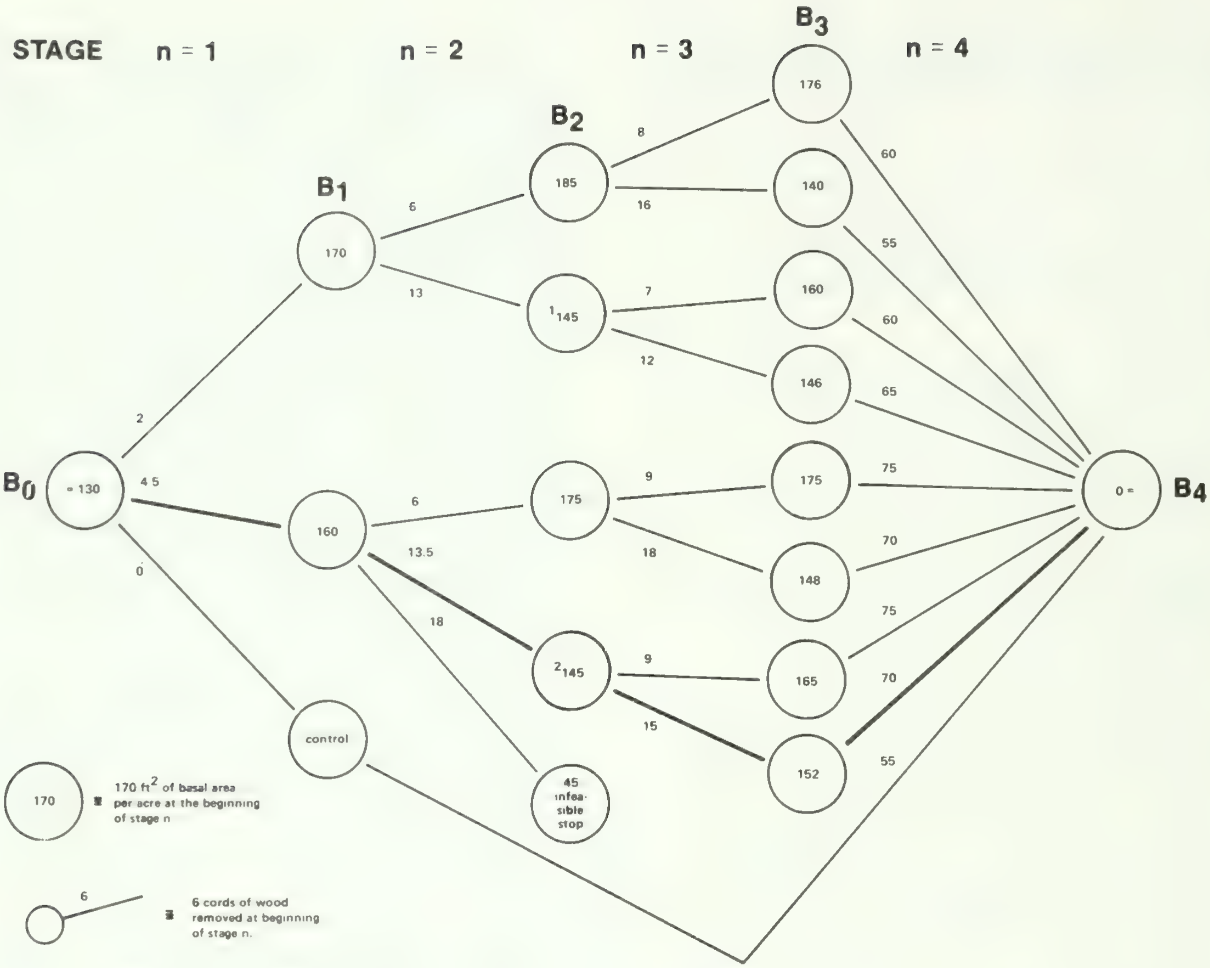


Figure 6. — *Network of simulated stand densities and harvest cuts for a four-stage process. Darkened line is the optimal cutting policy.*

nodes under B_2 that represent the system state at the beginning of stage three.

$$\text{For } n=3 \quad f_2(B_2) = \max_{Y_3} \left\{ V_3 + f_1(B_3) \right\}. \quad (15)$$

Again we evaluate equation (15) for every value of B_2 and, for each value of B_2, every value of Y_3. Thus,

$$f_2(185) = \max_{Y_3} \left\{ \begin{matrix} 8 + f_1(176) \\ 16 + f_1(140)^* \end{matrix} \right\} = \max_{Y_3} \left\{ \begin{matrix} 8 + 60 \\ 16 + 55^* \end{matrix} \right\} = 71$$

Comparing the sums (8 + 60) and (16 + 55), we choose the larger, and place a "*" to indicate that the 71 came from the route $f_2(185) \rightarrow f_1(140)$. Continuing for the remaining three nodes under B_2 gives

$$f_2(^1145) = \max_{Y_3} \left\{ \begin{matrix} 7 + f_1(160) \\ 12 + f_1(146)^* \end{matrix} \right\} = \max_{Y_3} \left\{ \begin{matrix} 7 + 60 \\ 12 + 65^* \end{matrix} \right\} = 77$$

$$f_2(175) = \max_{Y_3} \left\{ \begin{matrix} 9 + f_1(175) \\ 18 + f_1(148)^* \end{matrix} \right\} = \max_{Y_3} \left\{ \begin{matrix} 9 + 75 \\ 18 + 70^* \end{matrix} \right\} = 88$$

$$f_2(^2145) = \max_{Y_3} \left\{ \begin{matrix} 9 + f_1(165) \\ 15 + f_1(152)^* \end{matrix} \right\} = \max_{Y_3} \left\{ \begin{matrix} 9 + 75 \\ 15 + 70^* \end{matrix} \right\} = 85$$

For n=2

$$f_3(B_1) = \max_{Y_2} \left\{ V_2 + f_2(B_2) \right\}$$

$$f_3(170) = \max_{Y_2} \left\{ \begin{matrix} 6 + f_2(185) \\ 13 + f_2(^1145)^* \end{matrix} \right\} = \max_{Y_2} \left\{ \begin{matrix} 6 + 71 \\ 13 + 77^* \end{matrix} \right\} = 90$$

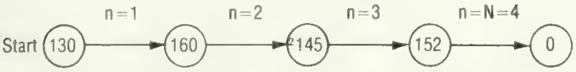
$$f_3(160) = \max_{Y_2} \left\{ \begin{matrix} 6 + f_2(175) \\ 13.5 + f_2(^2145)^* \end{matrix} \right\} = \max_{Y_2} \left\{ \begin{matrix} 6 + 88 \\ 13.5 + 85^* \end{matrix} \right\} = 98.5$$

For n=1 (the final solution stage)

$$f_4(B_0) = \max_{Y_1} \left\{ V_1 + f_3(B_1) \right\}$$

$$f_4(130) = \max_{Y_1} \left\{ \begin{matrix} 2 + f_3(170) \\ 4.5 + f_3(160)^* \\ 0 + \text{control} \end{matrix} \right\} = \max_{Y_1} \left\{ \begin{matrix} 2 + 90 \\ 4.5 + 98.5^* \\ 0 + 55 \end{matrix} \right\} = 103$$

Then, the optimal thinning schedule can be traced back through the nodes by locating the starred return functions as follows (see heavy line in fig. 6):



The associated returns (cord volume yields) are

$$4.5 + 13.5 + 15 + 70 = 103 \text{ cords/acre.}$$

$$\text{Note that } f_4(B_0) \equiv \sum_{n=1}^{N=4} V_n^* = 103 \text{ cords/acre.}$$

The basal areas that must be removed at the beginning of each stage to give these cord yields were omitted from figure 6 to avoid clutter. They are as follows: At the beginning of n=1, thin from 130 to 90 sq. ft., at the beginning of n=2, thin from 160 to 80 sq. ft., at the beginning of n=3, thin from 145 to 90 sq. ft., and at the beginning of n=N=4, clearcut (remove 152 sq. ft.).

Thus, total basal area harvested is 40 + 80 + 55 + 152 = 327 sq. ft./acre, to give 103 cords/acre. The reader is invited to find a thinning policy from among those shown in figure 6 that gives a greater total yield in cords per acre. If the problem involved more than four stages and more than two or three thinning intensities at the start of each stage, the number of alternative policies would increase rapidly, making the digital computer a necessity. Of course, the optimal path through the network is not necessarily **the** optimal way of thinning the stand; rather, it is the best from among the ways simulated. Now let's look at an approach that can be used to compute the exact optimal thinning intensity for each stage of a four-stage process.

CALCULUS SEARCH USING DP

In the previous example we dealt with a problem formulated in terms of discrete stages as well as discrete states. Now let's consider a problem formulated so there is a continuum of possible states at each stage (see fig. 2a,b, for comparison). The basic unknowns are the same as in the previous example: How much do we thin a stand, on a particular site, at each of four times so that we maximize total cordwood volume production? Figure 5a provides a geometric picture of what we know and what we need to determine.

We know:

B_0 = the initial basal area stocking of the stand,

B_4 = 0 because we want to clearcut at the beginning of stage four, so

Y_4^* = B_3 because the optimal decision is to cut as much as is present at the beginning of the last stage.

We assume:

V_n = the cordwood volume harvested at the beginning of stage n, or

= $\alpha H_{n-1} Y_n$, where

H_{n-1} = average height of trees removed at the beginning of stage n,

α = a model parameter, and

Y_n = basal area cut at the beginning of stage n.

An acceptable periodic basal area growth equation is given by

$$\Delta B_n = aS(B_{n-1} - Y_n) - b(B_{n-1} - Y_n)^m, \qquad (16)$$

$(B_{n-1} - Y_n)$ = residual stand basal area/acre at the beginning of stage n,

S = $(Si)^r$, where Si is site index, and

a,b,m = positive numerical constants.

We do not know:

$Y_n, (n=1,2,3)$ = the basal area to be removed in thinnings at the beginning of stages one, two, and three so that total yield is maximized.

Again we employ the functional recurrence equation for DP that implements a backward solution:

$$f_{N-(n-1)}(B_{n-1}) = \max_{0 \leq Y_n \leq B_{n-1}} \left\{ V_n + f_{N-n}(B_n) \right\} \qquad (17)$$

with $n = N, N-1, \ldots, 2, 1,$
$N = 4$, and
$V_n = R_n$ in equation (12).

Starting with n=4, we have

$$f_1(B_3) = \max_{Y_4} \left\{ \alpha H_3 Y_4 + f_0(B_4) \right\},$$

where $f_0(B_4) = 0$ because $B_4 = 0$. (Recall we clearcut at the beginning of stage 4, so in the equation

$$B_4 = (B_3 - Y_4) + \Delta B_4,$$

$$B_4 = (B_3 - Y_4) + g_4(B_3 - Y_4, \text{Site})).$$

But this is

$$B_4 = 0 + g_4(0, \text{Site}) = 0,$$

since $Y_4{}^* = B_3$, therefore

$$f_1(B_3) = \alpha H_3 B_3$$

We see this result characterized in figure 7a. The interpretation of this is, although we do not know the standing crop basal area at the beginning of stage four, we should cut all of it.

Now, with n=3,

$$f_2(B_2) = \max_{0 \leq Y_3 \leq B_2} \left\{ V_3 + f_1(B_3) \right\} \text{ ,or, from above,}$$

$$= \max_{0 \leq Y_3 \leq B_2} \left\{ \alpha H_2 Y_3 + \alpha H_3 B_3 \right\}. \qquad (18)$$

Our strategy is to express the quantity in brackets (equation 18) in terms of Y_3, or quantities that determine Y_3. Since $B_3 = B_2 - Y_3 + \Delta B_3$ (see fig. 3), we substitute as follows:

$$f_2(B_2) \quad \max_{Y_3} \left\{ \alpha H_2 Y_3 + \alpha H_3 (B_2 - Y_3 + \Delta B_3) \right\}, \text{ but}$$

$$\Delta B_3 = aS(B_2 - Y_3) - b(B_2 - Y_3)^m, \text{ giving}$$

$$f_2(B_2) = \max_{Y_3} \left\{ \alpha H_2 Y_3 + \alpha H_3 (B_2 - Y_3 + aS(B_2 - Y_3) - b(B_2 - Y_3)^m) \right\}. \qquad (19)$$

$$= \max_{Y_3} \left\{ \alpha \Theta_3 (Y_3) \right\}.$$

Now, the quantity in brackets, the quantity we want to maximize by selecting an appropriate value of Y_3, is expressed in terms of Y_3 and B_2 (ignoring the H_2 and H_3 that are determined outside the system). We can use ordinary calculus methods to obtain the value of Y_3 that maximizes

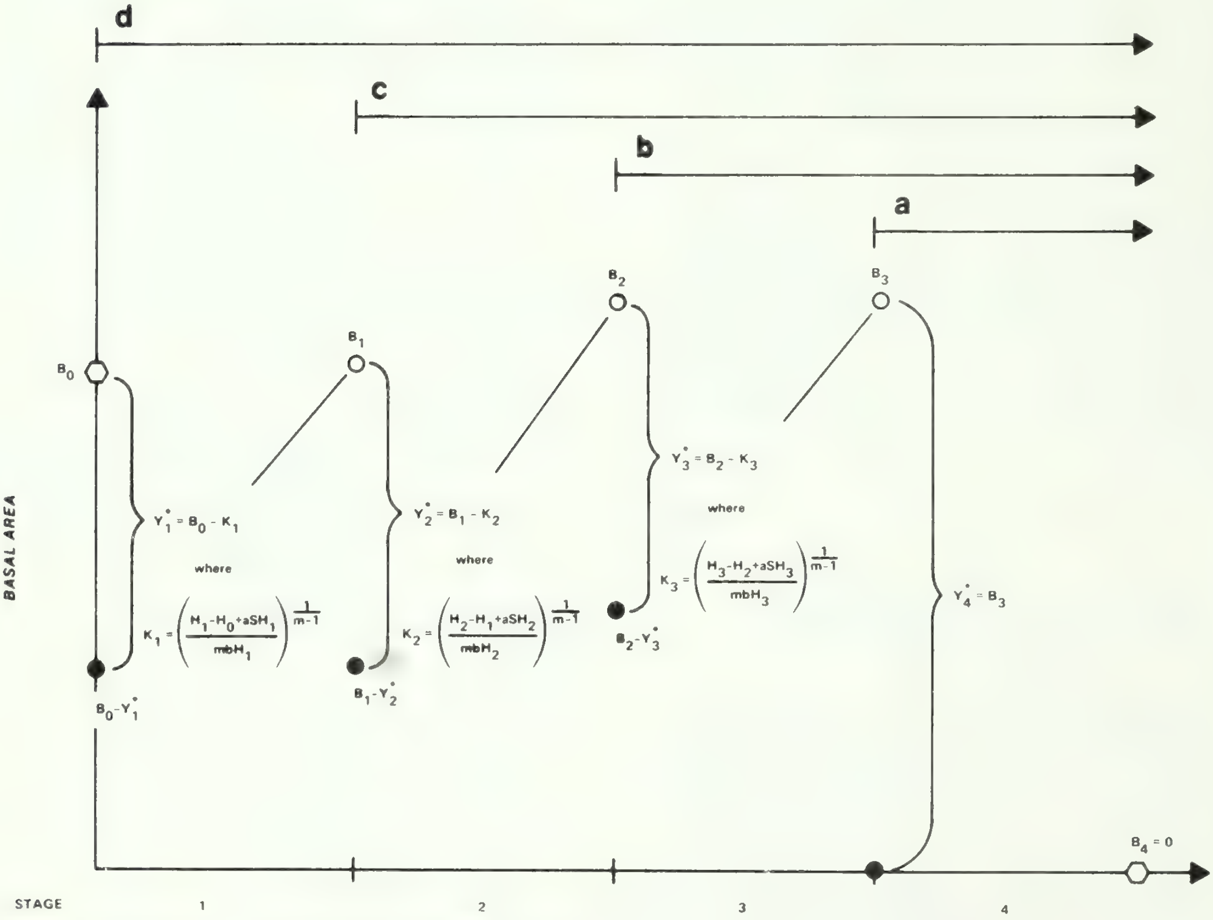

d
c
b
a
BASAL AREA
B_0
B_1
B_2
B_3
$Y_1^* = B_0 - K_1$
where
$K_1 = \left(\frac{H_1 - H_0 + aSH_1}{mbH_1}\right)^{\frac{1}{m-1}}$
$B_0 - Y_1^*$
$Y_2^* = B_1 - K_2$
where
$K_2 = \left(\frac{H_2 - H_1 + aSH_2}{mbH_2}\right)^{\frac{1}{m-1}}$
$B_1 - Y_2^*$
$Y_3^* = B_2 - K_3$
where
$K_3 = \left(\frac{H_3 - H_2 + aSH_3}{mbH_3}\right)^{\frac{1}{m-1}}$
$B_2 - Y_3^*$
$Y_4^* = B_3$
$B_4 = 0$
STAGE
1
2
3
4

Figure 7. — *Optimal amounts to thin,* $Y_n{}^*$, $n = 1 \ldots N$, *at the beginning of each stage. The amounts to thin are derived analytically at stage four first, stage three next, etc. Because of the repeating pattern of variables in the equation for* K_n, *the actual application of the formulas can proceed in a forward direction.*

Θ_3 by taking the partial derivative of Θ_3 with respect to Y_3, equating to zero and solving for Y_3:

$$\frac{\partial \Theta_3(Y_3)}{\partial Y_3} = 0.$$

This gives the value of Y_3 that maximizes Θ_3,

$$Y_3^* = B_2 - K_3,$$

$$\text{where } K_3 = \left(\frac{H_3 - H_2 - aSH_3}{mbH_3}\right)^{\frac{1}{m-1}} > 0, \text{ and}$$

$K_3 < B_2$ to be biologically meaningful.

This condition does not necessarily occur when B_2 is small. The problem generated if $K_3 > B_2$ implying a negative harvest, Y_3^*, will be discussed after the final solution to the dynamic programming problem has been derived.

A sufficient condition for a maximum rather than a minimum is that the second partial derivative of Θ_3 with respect to Y_3 is negative. It can be shown that this requires $a > 0$, $b > 0$, $Y_3 < B_2$ and $m > 1$. All these conditions generally hold. Since B_2 is the stand basal area at the end of the second stage, the thinning at the beginning of the third stage cannot affect B_2 (see fig. 3), so we assume $\partial B_2/\partial Y_3 = 0$. What the optimum value of Y_3, Y_3^*, does affect is the residual basal area at the beginning of stage 3, ΔB_3^*, V_3^*, Y_4^*, and V_4^*.

Substituting the optimal value of Y_3,

$$Y_3^* - B_2 - K_3,$$

back into equation (19) gives

$$\begin{aligned} f_2(B_2) &= \alpha(H_2(B_2 - K_3) + H_3(K_3 + aSK_3 \\ &\quad bK_3^m)), \text{ or} \\ &= \alpha(H_2(B_2 - K_3) + H_3P_3), \text{ where} \end{aligned}$$

$$P_3 - K_3 + aSK_3 - bK_3^m.$$

What is the optimal amount of basal area to thin at the beginning of stage three? It depends on the amount of standing crop present at the beginning of stage three (B_2) and K_3. And B_2 we do not yet know.

Getting on with the search, we let n=2,

$$\begin{aligned} f_3(B_1) &= \max_{0 \le Y_2 \le B_1} \left\{ V_2 + f_2(B_2) \right\} \\ &= \alpha \max_{Y_2} \left\{ H_1Y_2 + H_2(B_2 - K_3) + H_3P_3 \right\} \\ &= \alpha \max\ \Theta_2(Y_2), \end{aligned}$$

where $B_2 = B_1 - Y_2 + \Delta B_2 = T|B_1, Y_2|$.

$$\frac{\partial \Theta_2}{\partial Y_2} = 0 \text{ results in}$$

$$Y_2^* = B_1 - K_2,$$

$$\text{where } K_2 = \left(\frac{H_2 - H_1 + aSH_2}{mbH_2}\right)^{\frac{1}{m-1}} \geqslant 0.$$

Note that P_3 is not a function of Y_2 because of the volume return function and the growth model we used, so $\partial P_3/\partial Y_2 = 0$.

Then

$$f_3(B_1) = \alpha(H_1(B_1 - K_2) + H_2(P_2 - K_3) + H_3P_3),$$

where

$$P_2 = K_2 + aSK_2 - bK_2^m.$$

What is the optimal amount of basal area to thin at the beginning of stage two? It depends on how much is present to thin (B_1), and K_2; they depend on things we do not yet know. But, they are determined as follows, when

n=1

$$\begin{aligned} f_4(B_0) &= \max_{Y_1} \left\{ V_1 + f_3(B_1) \right\}, \text{ and} \\ &= \max_{Y_1} \left\{ \alpha H_0Y_1 + \alpha(H_1(B_1 - K_2) + H_2(P_2 - K_3) + H_3P_3) \right\}. \end{aligned} \quad (20)$$

where $B_1 = B_0 - Y_1 + \Delta B_1 = T_1|B_0, Y_1|$.

This results in the following optimal amount to thin at the beginning of stage one:

$$Y_1^* = B_0 - K_1,$$

$$\text{where } K_1 = \left(\frac{H_1 - H_0 + aSH_1}{mbH_1}\right)^{\frac{1}{m-1}} \geqslant 0.$$

Substituting Y_1^* into equation (20) gives the cumulative optimal return over four stages:

$$\begin{aligned} f_4(B_0) = \alpha\ (&H_0(B_0 - K_1) + H_1(P_1 - K_2) + \\ &H_2(P_2 - K_3) + H_3P_3), \end{aligned} \quad (21)$$

or

$$= \alpha(H_0(B_0 - K_1) + \sum_{n=1}^{N-1} H_n(P_n - K_{n+1})), \text{ with } K_N = K_4 = 0$$

$$\sum_{n=1}^{N=4} \alpha H_{n-1}Y_n^* - \sum_{n=1}^{N=4} V_n^*.$$

since

$$P_n = K_n + aSK_n - bK_n^m, \text{ and}$$

$$K_n = B_{n-1} - Y_n^*.$$

At last we know the optimal amount to thin at the beginning of the first period. This puts us in the position of being able to compute the optimal standing crop present at the start of stage two:

$$\begin{aligned} B_1^* &= B_0 - Y_1^* + \Delta B_1^*, \text{ or} \\ B_1^* &= B_0 - (B_0 - K_1) + \Delta B_1^*, \text{ where} \\ \Delta B_1^* &= aS(B_0 - Y_1^*) - b(B_0 - Y_1^*)^m, \text{ or} \\ \Delta B_1^* &= aS(B_0 - (B_0 - K_1)) - b(B_0 - (B_0 - K_1))^m \\ &= aSK_1 - bK_1^m, \text{ therefore} \\ B_1^* &= K_1 + aSK_1 - bK_1^m. \end{aligned}$$

The optimal amount to thin at the beginning of stage two is

$$\begin{aligned} Y_2^* &= B_1^* - K_2, \text{ or} \\ &= K_1 + aSK_1 - bK_1^m - K_2. \end{aligned}$$

The optimal standing crop at the beginning of stage three is given by

$$\begin{aligned} B_2^* &= B_1^* - Y_2^* + \Delta B_2^* \\ &= B_1^* - (B_1^* - K_2) + aSK_2 - bK_2^m \\ &= K_2 + aSK_2 - bK_2^m. \end{aligned}$$

The optimal amount to thin at the beginning of stage three is, then,

$$\begin{aligned} Y_3^* &= B_2^* - K_3, \\ &= K_2 + aSK_2 - bK_2^m - K_3, \text{ and} \end{aligned}$$

the optimal standing crop at the end of stage three is

$$\begin{aligned} B_3^* &= B_2^* - Y_3^* + \Delta B_3^* \\ &= B_2^* - (B_2^* - K_3) + aSK_3 - bK_3^m \\ &= K_3 + aSK_3 - bK_3^m. \end{aligned}$$

The final harvest cut, then, is

$$\begin{aligned} Y_4^* &= B_3^*, \\ &= K_3 + aSK_3 - bK_3^m. \end{aligned}$$

We can check our computations by summing the optimal harvest amounts and comparing this figure with the value of the functional recurrence relation $f_4(B_0)$. We note, however, that the latter is expressed in cords and the former in square feet.

Total basal area cut (thinnings + final harvest cut)

$$\begin{aligned} &(B_0 - K_1) \\ &+ K_1 + aSK_1 - bK_1^m - K_2 \\ &+ K_2 + aSK_2 - bK_2^m - K_3 \\ &+ K_3 + aSK_3 - bK_3^m \\ &= (B_0 - K_1) + \sum_{n=1}^{3} (K_n + aSK_n - bK_n^m - K_{n+1}) \\ &\text{with } K_4 = 0 \end{aligned}$$

Cordwood volume of total cut

$$\begin{aligned} &= \alpha H_0(B_0 - K_1) + \sum_{n=1}^{3} \alpha H_n(K_n + aSK_n - bK_n^m - K_{n+1}) \\ &\text{with } K_4 = 0 \end{aligned}$$

This agrees with the value given by equation (21).

DISCUSSION

Two conditions determine whether DP will yield an optimal policy. One condition, which applies to the total return function, must be met for every kind of multistage DP problem. Called the decomposition condition (see Nemhauser 1966), it was used in the previous two examples. The second condition states that DP is applicable only to multistage decision processes where: (1) the state at the end of stage n depends only on the state at the beginning of stage n, on the decision at the beginning of stage n, and on the stage; (2) the calculus-based search procedure is used. If our concern is with so-called stationary (nontime-dependent) processes, stage does not explicitly enter the determination of state. An example of a system where the state at the end of stage n depends on more than the immediately previous state is as follows

$$\begin{aligned} B_n &= B_{n-1} - Y_n + \Delta B_n \text{ where} \\ \Delta B_n &= g(B_{n-1}, B_{n-2}, B_{n-3}, Y_n, \text{Site}). \end{aligned}$$

In this case the stage transformation equation is

$$B_n = T_n[B_{n-1}, B_{n-2}, B_{n-3}, Y_n, \text{Site}], \text{ instead of}$$

$$B_n = T_n[B_{n-1}, Y_n, \text{Site}].$$

Although growth functions may be made more realistic by having historical components, adequate functions have been developed using only the previous state.

The severity of the restriction on stage-dependence is not what it first appears, because it applies only when one uses a calculus-based search procedure. We gave examples of a noncalculus-based search procedure and a calculus-based search. In the first example the stage dependence constraint does not apply, but in the second it does.

Although not addressed directly, the question of determining the optimal rotation age can be examined using the following equation from the previous section:

$$f_N(B_0) = \sum_{n=1}^{N} \alpha H_{n-1} Y_n^*. \tag{22}$$

By determining the numerical values of this function for several values of N it should be possible to estimate the number of stages that will maximize the optimal yield provided that the growth model possesses a biological limit as N becomes large. In a sense, we do a sensitivity analysis of equation (22) on N.

Conducting a sensitivity analysis on N is particularly easy in this case because of the way the same algebraic form is repeated in the equation for the optimal amount to thin, Y_n. In fact, we can, by simple induction, write the equation for any value of N, as follows:

for $n=N$, $B_N=0$, and $f_0(B_N)=0$ (assuming a clearcut at start of stage N)

$$V_N^* = \alpha H_{N-1} B_{N-1}, \text{ and}$$

for $n=N-1, N-2, \ldots, 3, 2, 1,$

$$Y_n^* = B_{n-1} - \left(\frac{H_n - H_{n-1} + aSH_n}{mbH_n}\right)^{\frac{1}{m-1}}, \text{ or}$$

$$= B_{n-1} - K_n \le B_{n-1}, \text{ with } K_n \ge 0.$$

The equation for the cumulative optimal return over $N-(n-1)$ stages is

$$f_{N-(n-1)}(B_{n-1}) = \alpha\left(H_{n-1}(B_{n-1} - K_n) + \sum_{n=n}^{N-1} H_n(P_n - K_{n+1})\right),$$

with $K_N = 0$, and
$P_n = K_n + aSK_n - bK_n^m$ for $n=n, n+1, \ldots, N-1$.
Recall

$$K_n = \left(\frac{H_n - H_{n-1} + aSH_n}{mbH_n}\right)^{\frac{1}{m-1}}$$

At the final solution stage, when $n=1$,

$$f_N(B_0) = \sum_{n=1}^{N} \alpha H_{n-1} Y_n^*.$$

By letting N=4, 5, 6, and 7, for example, and finding $f_4(B_0), f_5(B_0), \ldots, f_7(B_0)$, we can plot their respective values over the years corresponding to a rotation of four stages, five stages, etc. The optimal biological rotation age is reached in the forward solution when the average total return is maximized (maximum mean annual increment).

Let us return now to the problem of a negative harvest indicated when

$$Y_n^* = B_{n-1} - K_n < 0 \text{ because } K_n > B_{n-1}.$$

We can interpret K_n as the optimal residual basal area at the beginning of period n right after the thinning. If K_n is greater than the basal area at the end of stage $n-1$, this would indicate that the stand has not yet reached the optimal basal area for a biologically meaningful thinning. The manager has to wait until the stand has enough basal area to warrant a thinning, i.e., should not cut anything. Only at that time, derivation of an optimal dynamic programming solution becomes meaningful and the condition $K_n > B_{n-1}$ will not occur thereafter as long as net growth is nonnegative. To show this, consider any stage n at which

$$B_{n-1} > K_n$$

i.e., a thinning is biologically reasonable. The optimal residual basal area, K_n, becomes the base for additional basal area growth in the next stage. For the next thinning to be meaningful

$$B_n = K_n + \Delta B_n > K_{n+1} \text{ or } \Delta B_n > K_{n+1} - K_n.$$

Our experience with numerous derivation of optimal thinning schedules for varying initial conditions is that this condition holds after $B_{n-1} > K_n$.

The significance of the generality of the calculus approach made possible by using growth equation (16) is increased by the fact that the growth equation form is that of a modified Richards function (Richards 1959) that has been shown applicable to a variety of tree species (Pienaar and Turnbull 1973, Moser and Hall 1969).

The calculus search for an optimal cutting policy is likely to give a more precise estimate of cutting intensities than the network search. The latter finds the optimal combination of those cutting intensities simulated and entered in the network. A calculus-based search finds the exact optimal amount to cut at each cutting cycle, and is not dependent on what was simulated.

Comparing the recurrence equation indexing as used in this paper with what could be called the standard method of indexing (Bellman 1957) shows that the standard indexing is

$$f_n(B_n) = \max_{Y_n} \left\{ R_n + f_{n-1}(B_{n-1}) \right\}, \tag{23}$$

where $n = 1, 2, 3, \ldots, N$ (backward approach), and

$$B_{n-1} = B_n - Y_n + \Delta B_n.$$

The indexing introduced in this paper is

$$f_{N-(n-1)}(B_{n-1}) = \max_{Y_n} \left\{ R_n + f_{N-n}(B_n) \right\}, \qquad (24)$$

where n = N, N−1, . . . , 3,2,1 (backward approach), and

$$B_n = B_{n-1} - Y_n + \Delta B_n.$$

The importance of the new indexing method can be appreciated if we examine typical cases of backward solutions to several problems with different numbers of stages (fig. 8). The traditional approach (fig. 8a) begins by relabeling the periods backwards in time. Thus, the final time period is represented as n=1, no matter what the value of N. A continuing source of confusion with the standard indexing can be seen by examining the indexes above, say, growth period two. They are $f_4(B_4)$, $f_3(B_3)$, $f_2(B_2)$, and $f_1(B_1)$ for five-, four-, three-, and two-stage processes, respectively. The standard indexing only tells us how many growth periods from the end we have progressed.

The new indexing approach for the same set of problems is shown in figure 8b. No relabeling of periods is necessary, even though we are doing a backward solution. Let us again examine the indexes above growth period two, i.e., $f_4(B_1)$, $f_3(B_1)$, $f_2(B_1)$, and $f_1(B_1)$.

It can be seen that this method of indexing does the following:

(1) It preserves one's sense that states of the system, B_n, should have indexes that increase from left to right (see fig. 8b).

(2) The index, n−1, on, B_{n-1}, the state variable, is the same for the nth growth period no matter how many stages the problem involves.

(3) The index on f tells how many stages we have come from the Nth stage.

(4) The sum of the indexes on f and B gives the value of N.

(5) The index (n−1) on B_{n-1} in equation (24) indicates that the nth growth period starts with the state variable B_{n-1}, and this corresponds to the traditional stand basal area identity:

$$B_n = B_{n-1} - Y_n + \Delta B_n.$$

If, for economic or other reasons the basal area per acre removed must exceed a minimum amount, this new condition can be eliminated from

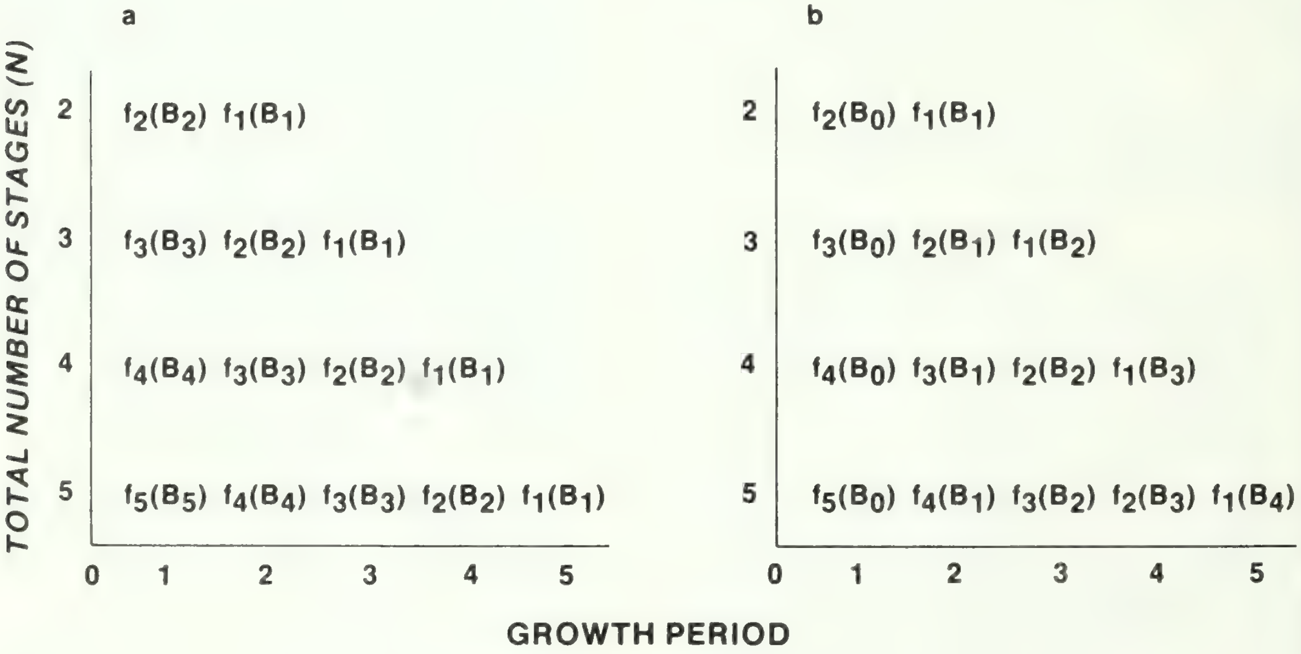

a
b
TOTAL NUMBER OF STAGES (N)
2
3
4
5
$f_2(B_2)$ $f_1(B_1)$
$f_3(B_3)$ $f_2(B_2)$ $f_1(B_1)$
$f_4(B_4)$ $f_3(B_3)$ $f_2(B_2)$ $f_1(B_1)$
$f_5(B_5)$ $f_4(B_4)$ $f_3(B_3)$ $f_2(B_2)$ $f_1(B_1)$
$f_2(B_0)$ $f_1(B_1)$
$f_3(B_0)$ $f_2(B_1)$ $f_1(B_2)$
$f_4(B_0)$ $f_3(B_1)$ $f_2(B_2)$ $f_1(B_3)$
$f_5(B_0)$ $f_4(B_1)$ $f_3(B_2)$ $f_2(B_3)$ $f_1(B_4)$
0
1
2
3
4
5
GROWTH PERIOD

Figure 8. — *Comparative indexes on the functional recurrence equation's lefthand side when using the standard DP approach (a) and the new approach (b) for a backward solution.*

the constraint equation by applying the Lagrangian multiplier method (see Nemhauser 1966).

CONCLUSIONS

Dynamic programming can be used to solve "optimal stand density over time" problems expressed in either of two forms: a network of simulated yields or a mathematical stand growth equation. With the former, one can use a noncalculus-based search procedure; with the latter, one can use a calculus-based search. When the stand growth model has the biologically reasonable form of the one suggested here, it is simple a matter to determine optimal stand density over any number of growth periods. This, in turn, makes it easy to determine the optimal rotation age by doing a sensitivity analysis of the total return on the number of stages in the decision process.

A new method is presented for indexing the functional recurrence equation of DP that makes it much easier to follow the solution procedure stage by stage.

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HOW TO DIAGNOSE BLACK WALNUT DAMAGE

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HOW TO DIAGNOSE BLACK WALNUT DAMAGE

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Illustrations by J. Lockyer

Black walnut trees, like all other plants, are susceptible to a variety of injuries that reduce or destroy their usefulness. The first step in preventing or controlling these injuries is to identify their cause. Most damage is caused by disease, insects, birds, mammals, or weather.

Presented here is a method for identifying the most common causes of injury to black walnut trees. It was developed primarily for use by walnut growers or foresters who are not specifically trained in insect or disease identification. The method features a "key" that leads the user step-by-step from the visual symptoms to the culprit responsible. Supplementing the key are brief descriptions of the damages and their causes, illustrated in most cases with line drawings.

Once the grower knows what is causing the problem, he can decide what can or should be done about it.

To identify all the insects and diseases that damage black walnut would be impractical and cumbersome. For example, more than 300 species of insects have been found on walnut in southern Illinois alone. So we have confined our efforts to those insects, diseases, and other sources of damage that are commonly found throughout most of the walnut-growing range and hence most likely to be encountered by the grower.

Some control measures are suggested. Generally, however, we refer the grower to the local service forester or county extension agent to find out about chemical control recommendations. This is because some chemicals currently used to control insects and diseases on black walnut may be banned or restricted by the Environmental Protection Agency in the future, thus making specific recommendations obsolete or illegal. Hence, we recommend that the grower always consult with the appropriate agencies before applying chemicals.

We have tried to keep technical terms and jargon to a minimum. Nevertheless, a few terms may still be present that are unfamiliar to some, so a brief glossary is included.

HOW TO USE THE KEY

1. **Examine the damage carefully.**
2. **Decide whether the damage is to**
   a. **foliage or nuts**
   b. **shoots, buds, or twigs**
   c. **trunk or stem**
3. **Turn to the appropriate heading in the key and work down through the alternatives.**

EXAMPLE: Yellow walnut leaf with brown spots

Select the proper category — Damage to Foliage and Nuts

Begin at A. Leaf has not been eaten, so go to B.

Read through each subheading under B.

Leaf fits description 4 ("Leaves with spots or blotches"); read through the subheadings under 4.

Damage fits the description under 4a, so it was caused by walnut anthracnose.

Compare the description and illustration of walnut anthracnose with the leaf sample.

If they do not agree, repeat the process or consult an expert.

DAMAGE TO FOLIAGE AND NUTS

A. LEAVES EATEN

1. Webbing on outer branch present in summer and early fall; webbing enlarges as season advances; caterpillars usually seen within webs. **FALL WEBWORM, p.4**
2. No webbing
    - a. Caterpillars present and found in groups feeding on edges of leaflets.
        - (1) Full-grown caterpillars hairy, dark purple to black, often with a white stripe along sides. **WALNUT CATERPILLAR, p.6**
        - (2) Full-grown caterpillars hairy, brick red to black with yellow stripes running the body length; a yellow bar present behind the head capsule. **YELLOW NECKED CATERPILLAR, p.6**
    - b. No caterpillars present
        - (1) Insects rarely seen feeding; oblong holes between veins in leaflets. **MAY BEETLES, p.5**
        - (2) Partially or completely eaten leaves; green or brown jumping insects may be seen. **GRASSHOPPER, p.4**

B. LEAVES DAMAGED BUT NOT EATEN

1. Young leaves drooping, later turn brown or black. **FROST DAMAGE, p.19**
2. Leaves stippled, often with some surface distortion; many dark-colored insects may be present on lower surface of leaflets, some with lacy appearance. **WALNUT LACE BUG, p.9**
3. Leaves crumpled or distorted
    - a. Leaf stem or leaflets severely crumpled and distorted, especially in spring; later in the season damaged parts may turn reddish and with a velvety texture. **MITES, p.7**
    - b. Leaflets cupped or moderately distorted, numerous greenish-colored 1/16- to 1/8-inch-long insects may be present on under surface of leaflets. **APHIDS, p.7**
4. Leaves with spots or blotches
    - a. Leaflets pale with irregular dark brown to black spots, often bordered with yellow. **WALNUT ANTHRACNOSE, p. 15**
    - b. Leaflets with white, "powdery" substance on upper surface. **POWDERY MILDEW, p.14**
    - c. Leaflets with small white circular spots on under leaf surface. **DOWNY LEAFSPOT, p.14**
    - d. Leaflets with regular brown spots, often with concentric rings like a "bulls eye" target. **TARGET LEAFSPOT, p.15**

C. DAMAGE TO NUTS

1. Nuts covered with small, dry, dark, sunken areas. **WALNUT ANTHRACNOSE, p.15**
2. Nuts with large, moist, dark, sunken areas. **HUSK MAGGOT/HUSK FLY, p.13**
3. Nuts with dark, crescent-shaped excavation near blossom end. **BLACK WALNUT CURCULIO, p.13**

DAMAGE TO BUDS, SHOOTS, AND TWIGS

A. EXPANDING BUDS DAMAGED, EARLY SPRING

1. Bud or expanding leaflets partially eaten; bud and elongating shoot solid, not hollowed out; insects rarely seen feeding. **MAY BEETLES, p.5**
2. Buds or expanding leaflets contain small holes; a small pile of insect droppings often present near hole; bud or shoot hollowed out; may contain drab, olive-green caterpillar with black head. **WALNUT SHOOT MOTH, p.14**

B. ELONGATING SHOOTS DAMAGED, MID TO LATE SPRING

1. Small, black, trumpet-shaped case attached to leaf stem; may contain drab, olive-green caterpillar with black head.
   PECAN LEAF CASEBEARER, p.5

C. SMALL TWIGS AND BRANCHES DAMAGED BY INSECTS LAYING THEIR EGGS BENEATH THE BARK

1. Long, jagged scars, up to several inches long, on larger twigs; shredded wood fibers may be visible and hanging from scars; large red-eyed insects may be present on trees. **CICADAS, p.8**
2. Small 1/8-inch oval slits or depressions in bark of smaller twigs; small brown insects with two cream-colored spots behind a forward projecting hump may be present; insects capable of jumping.
   TWO-MARKED TREEHOPPERS, p.9
3. Zipper-like slits up to 1 inch long in bark of smaller twigs; no shredded wood fibers visible. **PLANT HOPPERS, p.8**

D. TERMINAL BUDS MISSING OR BROKEN OFF IN YOUNG TREES

1. Main branches, especially main stem, broken and usually hanging.
   BIRDS, p.19
2. Buds and young twigs nipped off; completely missing. **DEER, p.17**

DAMAGE TO TRUNK AND STEM

A. BARK REMOVED OR HANGING IN SHREDS ON STEMS OF YOUNG TREES

1. Bark hanging in shreds; no "teeth marks" on exposed wood. **DEER RUB, p.17**
2. Bark not hanging in shreds; exposed wood is rough with "teeth marks".
   RODENT DAMAGE, p.18
   (e.g. rabbits, mice, squirrels)

B. BARK ON TRUNK SEVERELY PERFORATED

1. Pinholes about 1/32 inch in diameter usually found in darkened, dead areas of lower trunk; may also be found in small twigs or branches; often associated with *Fusarium* canker.
   AMBROSIA BEETLES, p.12
2. Holes larger, about 3/16 inch in diameter; not found in dead areas of trunk; usually form a partial to complete circle around upper trunk near branches.
   BIRDPECK, p.18

C. CRACKS OR OPENINGS IN BARK

1. Cracks in bark depressed or flattened and darkened in areas.
   a. Usually evident near groundline on small diameter trees; tree normally dying back to depression then resprouting below dead area.
      FUSARIUM CANKER, p.16
   b. Evident around wounds or branch stubs on trees of all sizes, later developing target-shaped areas in wood; affected area enlarging each year.
      NECTRIA CANKER, p.17
2. Cracks or openings not depressed, exposing hollow areas or unsound wood; fruiting bodies may be extruding from the tree.
   DECAY, p.19
3. Bark peeling away; large tunnels in wood and bark, filled with sawdust; white, legless larvae with broad flat heads present beneath bark and in tunnels.
   FLAT-HEADED APPLE TREE BORER, p.12

D. DEAD BRANCHES IN CROWNS OF LARGER TREES; normally an indication of root rot, poor site, herbicides, soil compaction, climatic stress, etc.

DIEBACK, p.19

DEFOLIATORS /LEAF FEEDERS

This broad category includes several different kinds of insects. All defoliators have chewing mouthparts that allow them to eat the leaves of trees and other plants. Entire trees may be defoliated. Impact of defoliation on black walnut is not completely understood but tree vigor is probably reduced, growth slowed, and the defoliated trees may become more susceptible to attack by other insects or diseases.

FALL WEBWORM,

HYPHANTRIA CUNEA (DRURY)

Description

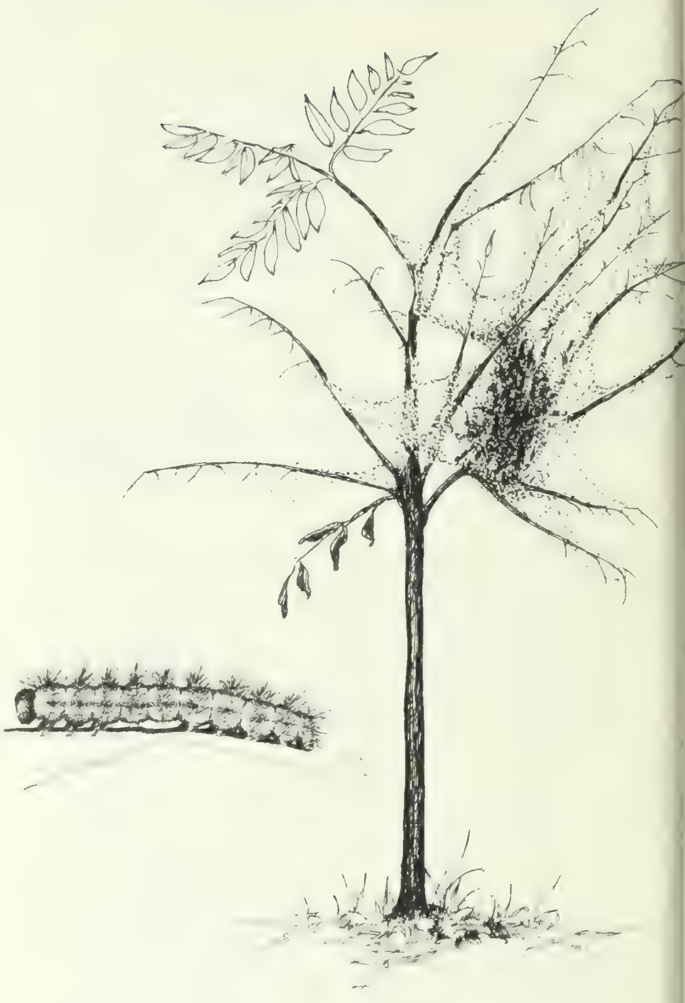
The fall webworm is widely distributed throughout eastern United States and feeds on a wide variety of hosts. It is easily recognized by its characteristic web, which encloses one or more branches of a tree and sometimes an entire small tree. Webs begin appearing about mid-July on the outer tips of branches. As the summer progresses, the webs enlarge and become more noticeable. The larvae live inside the web, as many as several hundred to a colony. Very young larvae feed only on the cells of the upper surfaces of leaves but as they grow older they consume entire leaves. Full-grown larvae are usually pale yellow or green with a broad dark stripe down the center back and a yellow stripe down each side. The body is covered with gray or red hairs that measure about 1 inch long. The adult is a white moth with dark spots on the wings.

Injury

When the insect is abundant, whole trees may be enclosed within webs and eventually defoliated. Defoliation several years in a row may weaken the tree and slow its growth. Defoliated branches are normally not killed and will leaf out again, sometimes within a few weeks.

Control

Remove webbing and caterpillars by hand when they first become noticeable. It is not necessary to remove the branches. Repeated defoliation over several years' time may require chemical control. Consult your local county extension agent for recommended controls.



GRASSHOPPERS

Description

Several species of grasshoppers have been reported feeding on black walnut. Grasshopper nymphs and adults are green-colored insects with long hind legs designed for jumping. Adults may be as long as 2 inches.

Injury

Grasshoppers feed on leaves and are not normally considered a serious pest. However, if a walnut plantation is adjacent to an open field that is cut periodically to produce hay or some other crop, the grasshoppers may move over to the walnut trees after the field crop has been cut.

Defoliation of trees may occur when grasshopper populations are high.

Control

If possible, do not grow black walnut trees near open fields where high grasshopper populations are common. Otherwise, consult your county extension agent for recommended controls.

MAY BEETLES,

PHYLLOPHAGA SP.

Description

May beetles, also known as June beetles or June "bugs", are found throughout eastern United States.

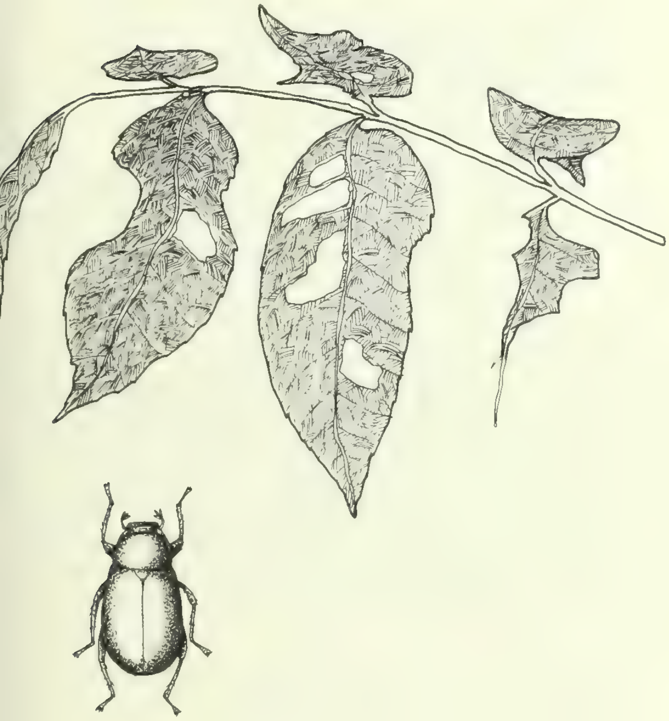
The adults are oval, robust insects that range in color from light straw to dark brown and in size from 1/2 to 3/4 inch long. The larvae, known as grubs, are milky white and C-shaped; they live underground and feed on plant roots. Adults are most often seen at night flying around lights or into windows and screens during late April, May, and June.

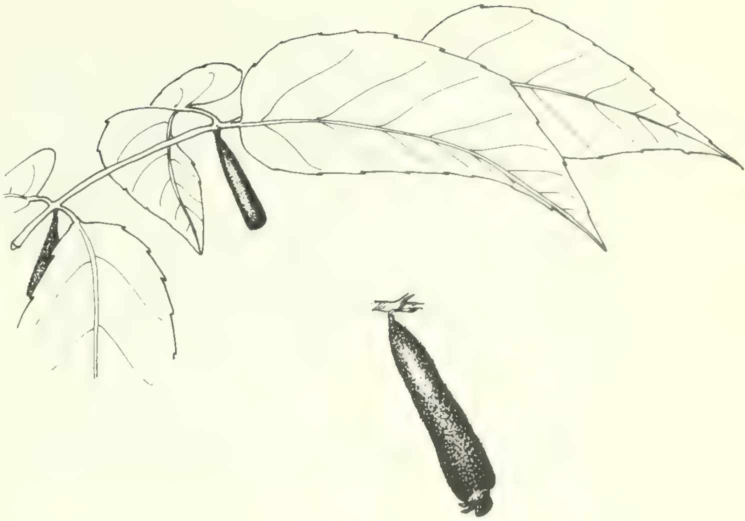
Injury

The adults feed at night on the newly expanding buds and leaflets of black walnut and other trees. Entire buds may be killed. The beetles also chew holes in already expanded leaves, causing the characteristic shot-hole effect in young leaves in early spring.

Control

Usually no control is necessary.





PECAN LEAF CASEBEARER,

ACROBASIS JUGLANDIS (LeBARON)

Description

The pecan leaf casebearer, which is closely related to the walnut shoot moth, is a much less serious pest of black walnut. Both species are commonly found in the same plantation. Because they are nearly identical in appearance, they are best distinguished by their feeding habits.

Larvae are drab, olive-green with a black head capsule. They grow to 3/4 inch long. Adults are gray-brown moths.

Newly hatched larvae overwinter in protective cases near the terminal bud. In early spring the larvae leave their cases and move to buds where they begin chewing on the outer surface of the bud scale. Feeding continues as the bud expands. A pile of excrement may conceal a feeding larva but the larva never bores inside the bud. As the larvae grow older and the leaf grows larger, the larvae move to about the middle of the leaf and construct a black trumpet- or cone-shaped case around themselves. From the case, which remains attached to the undersurface of the leaf stem, larvae feed on walnut leaflets.

Injury

A small amount of defoliation may occur in a tree heavily infested with the pecan leaf casebearer. Normally, however, these insects cause little damage to expanding buds or to leaflets.

Control

No control is recommended.

WALNUT CATERPILLAR,

DATANA INTEGERRIMA
GROTE & ROBINSON

Description

The walnut caterpillar is a common pest of black walnut trees throughout eastern United States. The larvae are gregarious, often found in masses on the trunks of trees or feeding on the foliage.

Very young caterpillars are red with grayish-white hairs covering the body. Full-grown caterpillars are as long as 2 inches and have a black body with longitudinal yellow stripes along their sides. The entire body is covered with long white hairs.

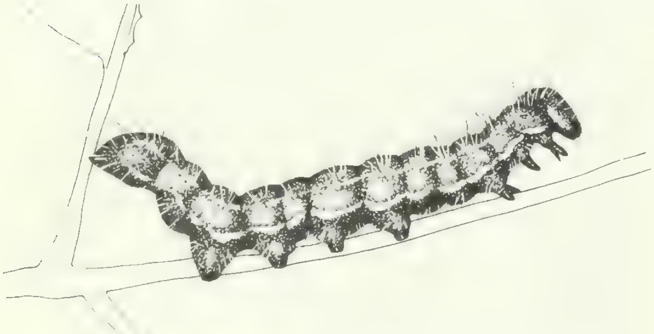
The adult moth is brownish gray and has a wingspread of nearly 2 inches. The front wings are marked by curving transverse dark lines.

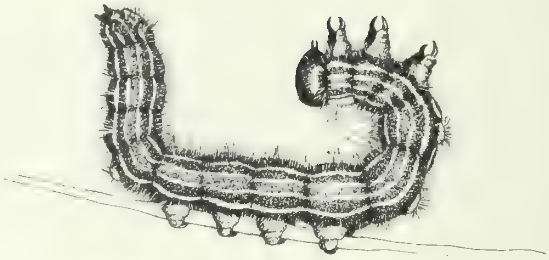
Injury

Young caterpillars eat only the outer layer of cells on the lower leaf surface; older larvae consume the entire leaf. Walnut caterpillars are gregarious and feed in colonies. One colony can defoliate an entire young tree in a short time. Often they seem to move down a line of walnut trees, stripping each of its leaves in turn.

Control

Hand removal of young caterpillars is most effective in preventing further defoliation. If this is impractical, consult your service forester or county extension agent for recommended chemical control.





YELLOW-NECKED CATERPILLLAR,

DATANA MINISTRA (DRURY)

Description

The yellow-necked caterpillar is closely related to the walnut caterpillar. It feeds on black walnut as well as other forest trees throughout most of the eastern United States.

Full-grown larvae of the yellow-necked caterpillar are about 2 inches long with a black body and black head. The "neck" area behind the head is characterized by a bright orange-yellow spot. The remainder of the body is marked with four longitudinal yellow stripes interspersed with black, and the entire body is clothed with long, soft, white hairs. The larvae are gregarious and feed in large colonies on leaves near the tips of twigs and branches.

Injury

Occasional outbreaks of the yellow-necked caterpillar may completely defoliate black walnut trees.

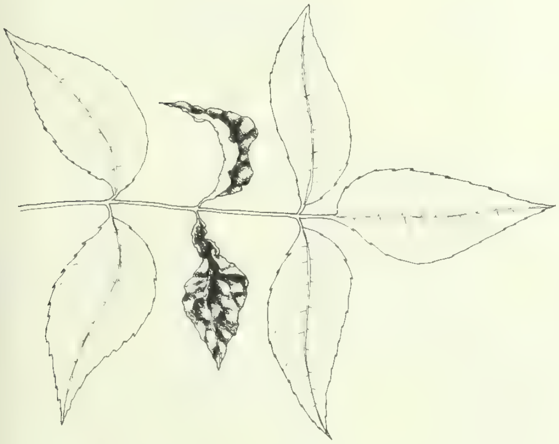
Control

When outbreaks occur, consult your local county extension agent for recommended chemical controls. Removing larvae by hand is also effective.

SUCKING INSECTS OR MITES

This category includes those insects that insert their mouthparts into a leaf or twig and suck the juices from the plant. The tree's reaction is manifested by wilted or curled leaves, galls, defoliation, branch tip dieback, or reduced growth. Determining the cause of these symptoms usually depends on identifying the insect itself.

Mites are tiny 8-legged, spider-like "bugs" closely related to insects. They have piercing-sucking mouthparts and cause damage resembling that produced by sucking insects. Expert identification is often necessary to distinguish between the two.



VELVET GALL MITE,

ERIOPHYES CAULIS KEIFER

Description

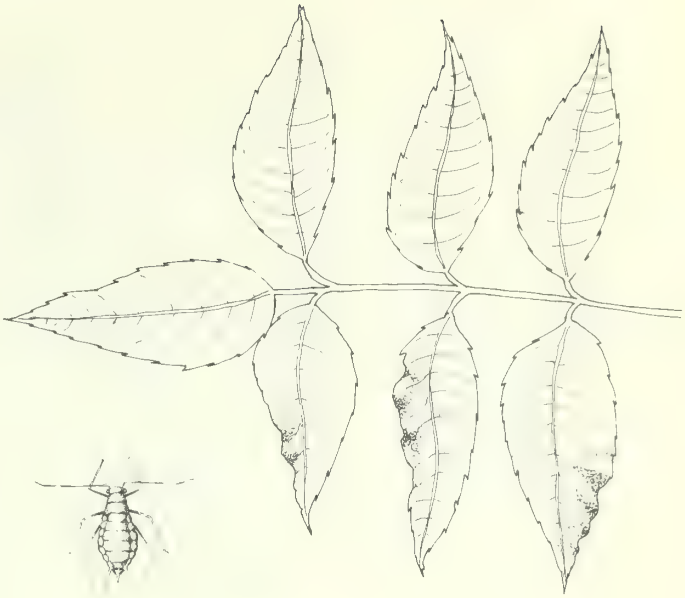
Little is known about the mites that occur on black walnut, but the velvet gall mite is common in some areas. The mite itself is so small that it cannot be seen with the unaided eye.

Injury

The velvet gall mite causes a conspicuous velvety red growth up to an inch long on the leaf stem, often causing the leaf to curl or twist over on itself. Galls may be numerous on individual trees but they are considered to be harmless to the tree.

Control

No control is recommended.



APHIDS OR PLANT LICE,

MONELLIA SP. AND *MONELLIOPSIS* SP.

Description

Several species of aphids are found on black walnut. They are a common, widely distributed insect pest and occur wherever walnut is grown. They occur throughout the growing season on the undersurface of walnut leaves.

Aphids are small, soft-bodied insects with pear-shaped bodies; they may be brown, green, white, or purple in color. Not all adult aphids have wings but when present the wings are transparent. The nymphs resemble the adults in color and shape but are smaller in size.

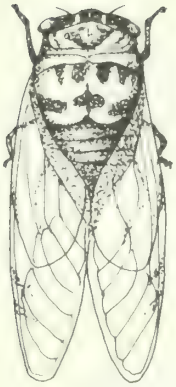
Injury

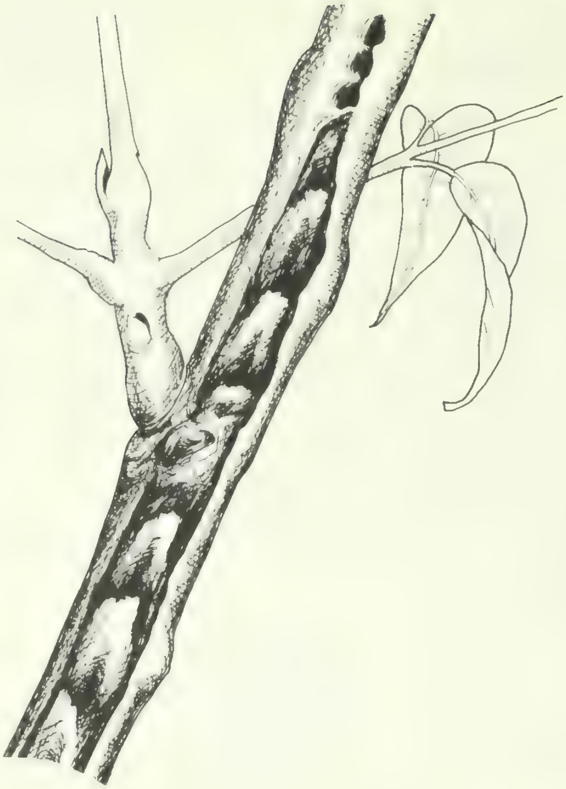
Aphids suck the juices from leaves and often deposit a sticky substance called "honey-dew" on the leaf surface. Later, the surface of the leaves may turn black in response to a fungus that grows on the honey-dew. This condition, known as "sooty-mold", may prevent light from reaching the leaf surface and thus reduce photosynthesis.

Normally, aphids are sparse on black walnut and therefore probably cause little damage. However, if conditions permit, populations can become large. Symptoms of aphid activity include curling of leaves, yellowing, defoliation, reduction of growth, and, in extreme cases, branch dieback.

Control

No control is recommended unless serious damage occurs. Then consult your local county extension agent for chemical controls.





CICADA,

MAGICICADA SP.

Description

The periodical cicada is also known as the 13-year (*Magicicada tredecassini* Alex. & Moore) or the 17-year (*M. septendecim* (L.)) locust, appearing in great numbers every 13 years in the South and every 17 years in the North. Periodical cicadas are widely distributed throughout eastern United States.

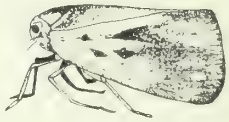
Adult cicadas are large, dark, heavy-bodied insects with membranous wings and red eyes. The females possess a strong ovipositor. Adult cicadas can reach 1-1/2 inches in length. Nymphs live in the soil, feeding on plant roots, and so are rarely seen. Adult male cicadas produce a characteristic sound by vibrating their wings against their body.

Injury

Injury to black walnut trees is caused by the adult female as she uses her ovipositor to make jagged slits in the bark and wood of twigs and small branches. Shredded wood fibers may be seen protruding from the slits. Affected twigs and branches are weakened and commonly break off in strong winds. Oviposition scars may be visible for several years after the injury was made.

Control

No controls are recommended.



PLANT HOPPERS

Description

Several species of plant hoppers have been found on black walnut, the most common of which are *Anormenis septentrionalis* (Spinola) and *Metcalfa pruinosa* (Say).

The nymphs of both species are similar in color and size. They resemble small fluffy masses of cotton because of white waxy secretions they deposit around themselves and on the plant. Adults of *Metcalfa pruinosa* are dark blue-black in color, sometimes with a white powdery substance obscuring the color. *Anormenis septentrionalis* adults are green to yellow-green. Both species are approximately 1/4 inch long and they hold their wings flat against the sides of their bodies. Plant hoppers are noted for their ability to jump when disturbed.

Injury

Adults and nymphs are sucking insects, feeding on sap taken from leaves and stems of smaller twigs. Feeding damage is considered insignificant. The female adult, however, may cause the tips of small twigs to die when she deposits her eggs in zipper-like slits beneath the bark.

Control

Control is usually not necessary.

2-MARKED TREEHOPPER,

ENCHENOPA BINOTATA (SAY)

Description

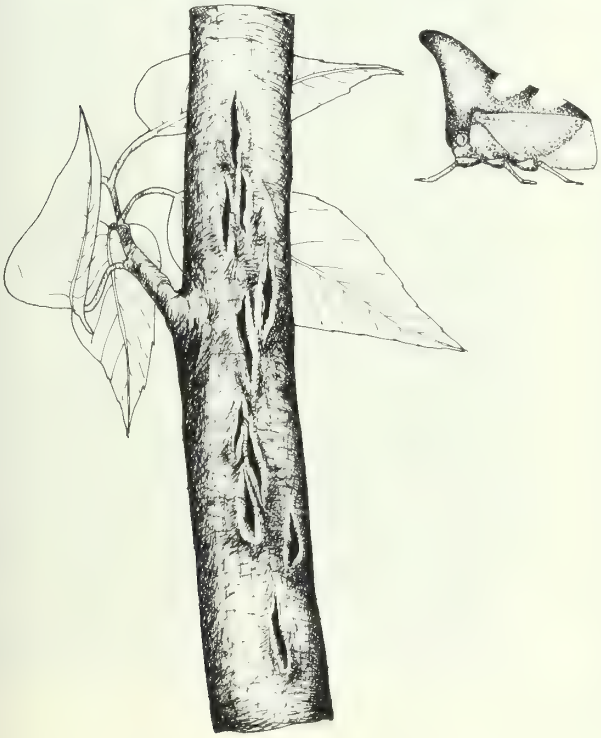
The 2-marked treehopper is a small, dark-brown insect with two yellow spots on the center of its back. It has a thorn-like projection over the head and jumps when disturbed. Adults are approximately 1/4 inch long. The nymphs are black with white markings and often have spine-like structures extending from their abdomens. Treehoppers are widely distributed throughout eastern United States.

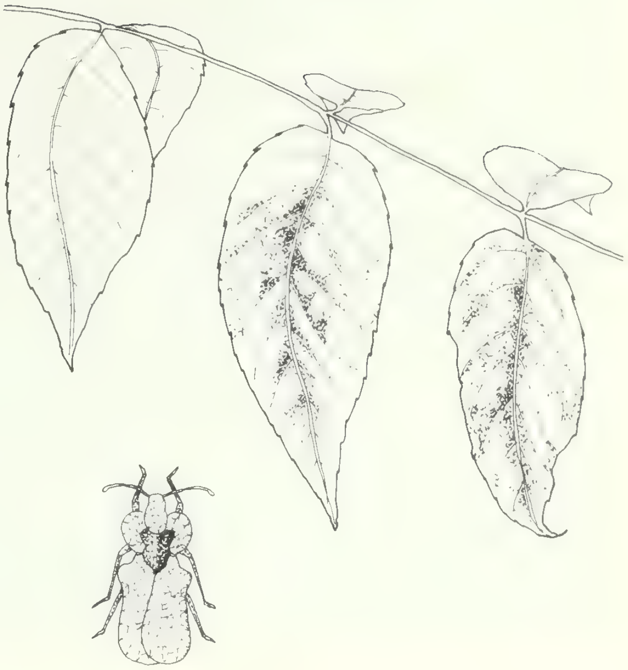
Injury

Both adults and nymphs suck sap from walnut leaves. Often they can be seen feeding on the lower leaf surface or on the leaf rachis. Although they may be abundant within a plantation, their feeding habits do not appear to cause serious damage. However, female adults can damage twigs when they deposit eggs into small slits made by their ovipositors. After the eggs are laid the female covers them with a white frothy "plug" that later turns brown. After the eggs hatch, the slits remain evident as scars for several years. Treehoppers are present on walnut trees throughout the growing season.

Control

Control is usually not necessary.





WALNUT LACE BUG,

CORYTHUCA JUGLANDIS (FITCH)

Description

The walnut lace bug feeds almost exclusively on black walnut and is found throughout the range of black walnut.

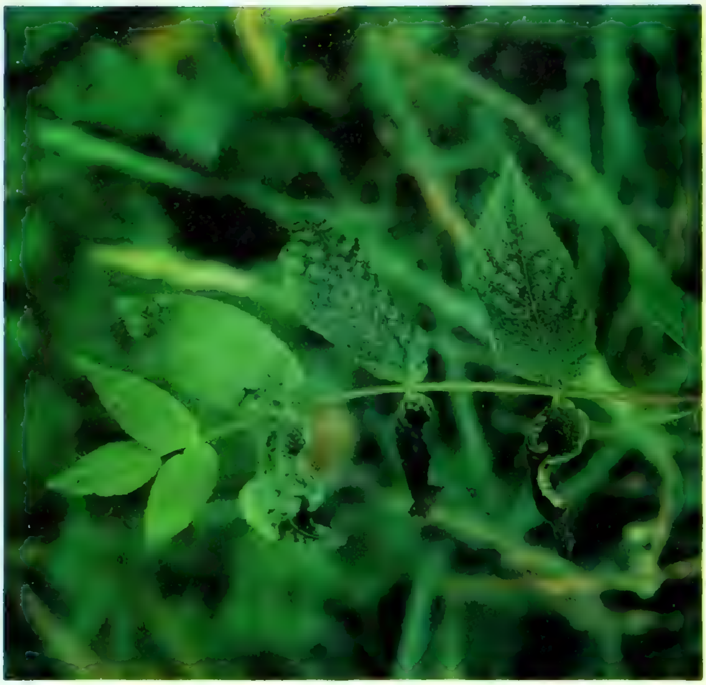
It is so named because of the adult's lacy wingcovers. The head is covered with a lace-like, arching hood. Adults are about 1/5 inch long and have transparent white wingcovers with dark bodies. The nymphs are much smaller, dark brown in color, and oval-shaped.

Injury

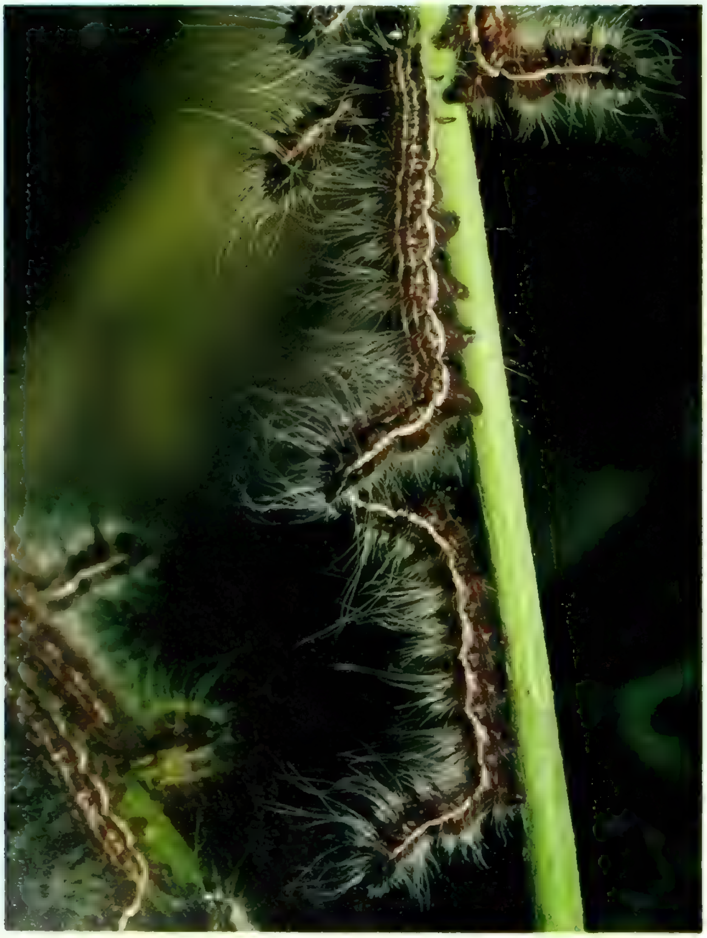
Both adults and nymphs are found together on the lower surfaces of walnut leaflets where they suck the sap from the leaves. More than 100 nymphs and adults may be present at one time on one leaflet. Areas where they have fed are easily recognized because of cast skins, excrement, and dark, discolored patches of leaf. The upper leaf surface is stippled with tiny white spots that give the upper leaf surface a whitish appearance. Leaves of heavily infested trees may turn brown and fall off.

Control

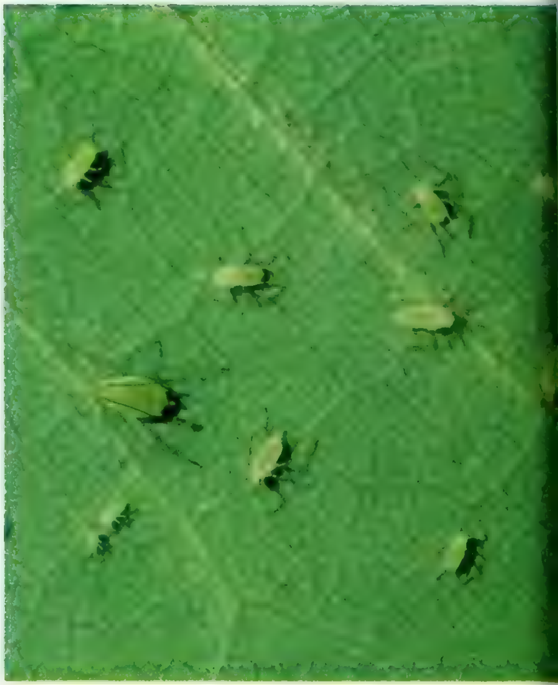
Consult your local service forester or county extension agent for the recommended control methods.



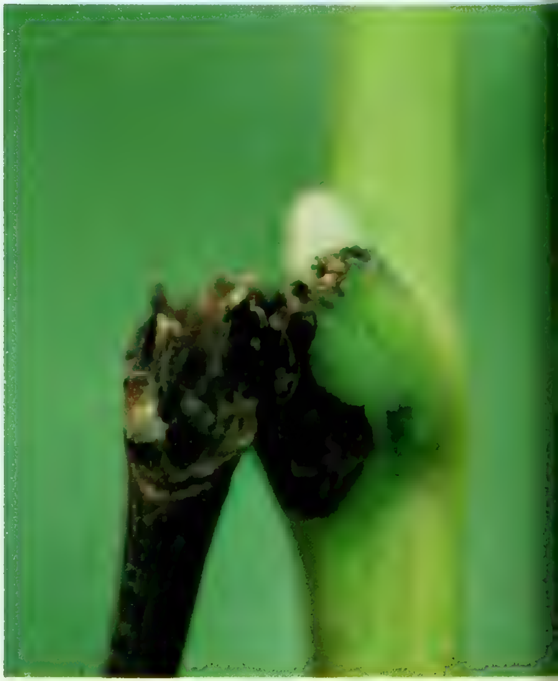
Velvet gall mite damage



Walnut caterpillar (early stage)

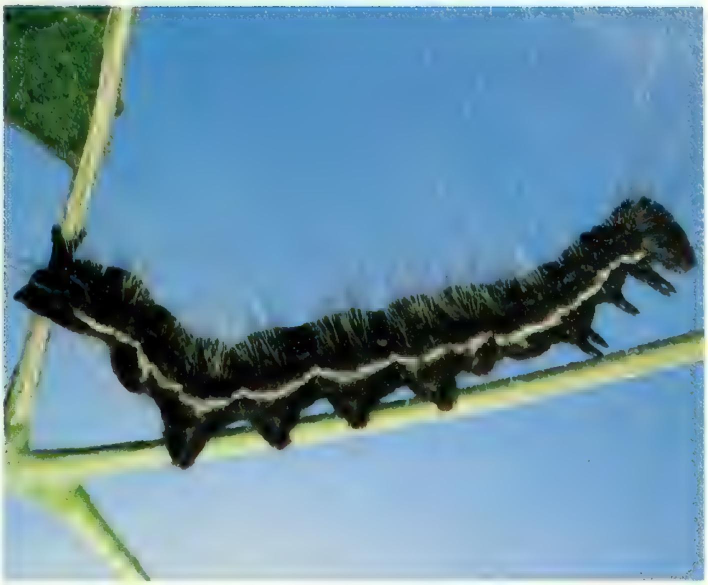


Aphids on black walnut

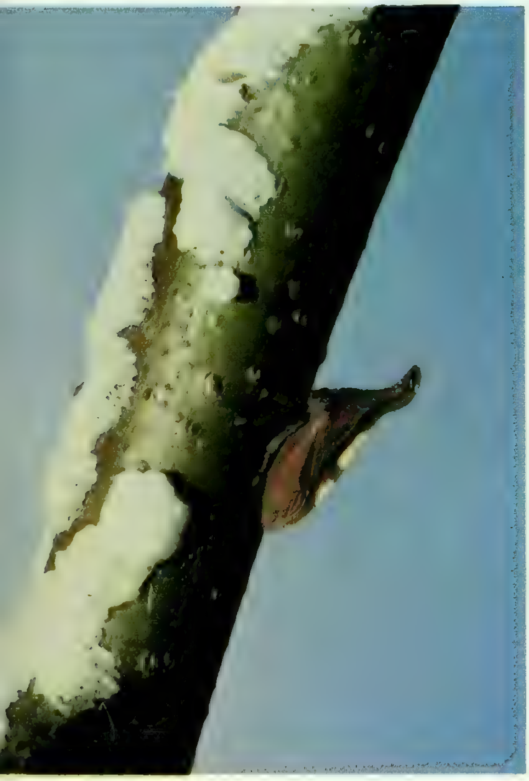


Weevil dam

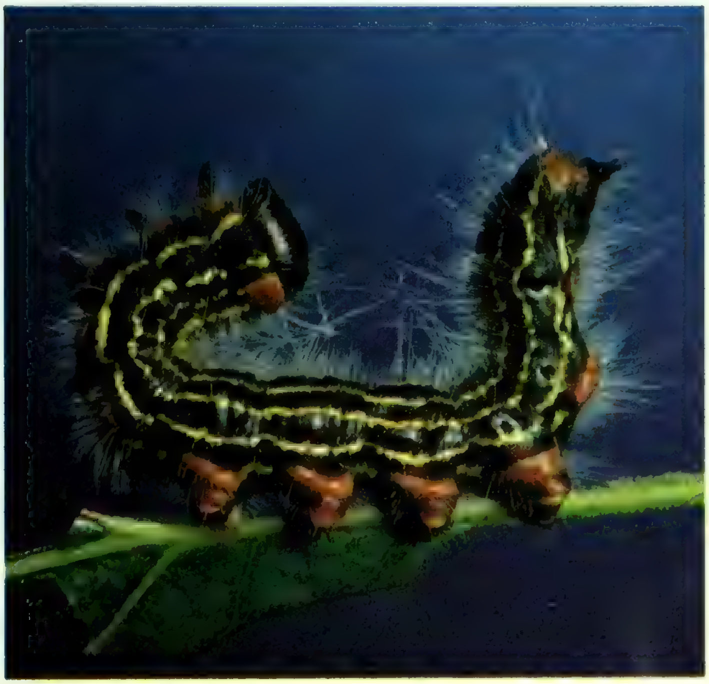
damage



Walnut caterpillar (late stage)



Two-marked treehopper



Yellow-necked caterpillar

BORING INSECTS

Some boring insects attack buds or other soft plant parts; others bore into the wood itself. Bud borers are perhaps the most serious insect pests of black walnut because they can kill terminal buds and cause multiple forking in a young tree, destroying its value for veneer or high quality timber. Insects that bore directly into wood usually attack only weakened, dying, or dead trees.

AMBROSIA BEETLES

Description

At least two species of ambrosia beetles attack black walnut trees but the most serious is *Xylosandrus germanus* (Blandf.). This beetle occurs throughout most of the northeastern and north-central walnut growing regions.

The adult female beetle is dark brown to black and about 1/8 inch long. The immature stages are rarely seen because they occur in tunnels made inside the wood by the adult female. External entrance holes to these tunnels are about 1/32 inch in diameter, and are sometimes referred to as pinholes.

Injury

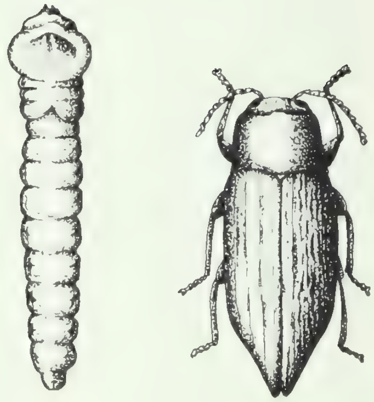
Young walnut trees up to 8 years old are most often attacked.

A *Xylosandrus germanus* female may introduce a *Fusarium* fungus into the tree as she excavates her tunnel into wood. This fungus causes a cankered area in the wood, usually causing top dieback and resprouting from the base of the tree. Cankering, however, is not always apparent. In some plantations, dieback in 1 year due to ambrosia beetle/*Fusarium* canker attack has been reported on 30 to 40 percent of the trees.

Ambrosia beetle attack is usually not detected until there is profuse sprouting from the base of the trees or until the trees are dead. Close examination is necessary to locate the tiny pinholes in the lower stem area or in small, low-hanging branches.

Control

Cut and remove dead or *Fusarium*-canker-infected tree tops and branches and burn, if possible.



FLAT-HEADED APPLE TREE BORER,

CHRYSOBOTHRIS FEMORATA (OLIV.)

Description

The flat-headed apple tree borer is a common insect in the eastern United States, attacking primarily apple trees but also black walnut.

The adult beetle is flat with a dark-green bronze back and a metallic brassy color on its abdomen. The body is bullet-shaped, ranging in length from 1/3 to 2/3 inch. The wing covers are usually marked with two, wavy, depressed, light-colored bands.

Full-grown larvae have flat, broad heads and yellowish white bodies about 1 inch long.

Injury

Adults feed on the foliage of trees but the larvae feed in the phloem and outer sapwood area. They make large tunnels, sometimes several inches long. The flat-headed apple tree borer often attacks newly planted trees or trees weakened or stressed by drought, defoliation, or disease, thus hastening the tree's decline.

Control

Maintain tree vigor by pruning dead or diseased branches and fertilizing the soil if nutrients are limiting. Wrap trunks with high-grade wrapping paper or burlap when trees are planted or pruned to prevent female beetles from laying eggs.

WALNUT CURCULIO,

CONOTRACHELUS RETENTUS (SAY)

Description

The walnut curculio is commonly found throughout eastern United States wherever walnut trees are grown.

The adult curculio is about 1/5 inch long and is reddish-brown with two small, white spots on its wing covers. It has a long snout with which it feeds. The larvae are small, legless, and a dirty white in color.

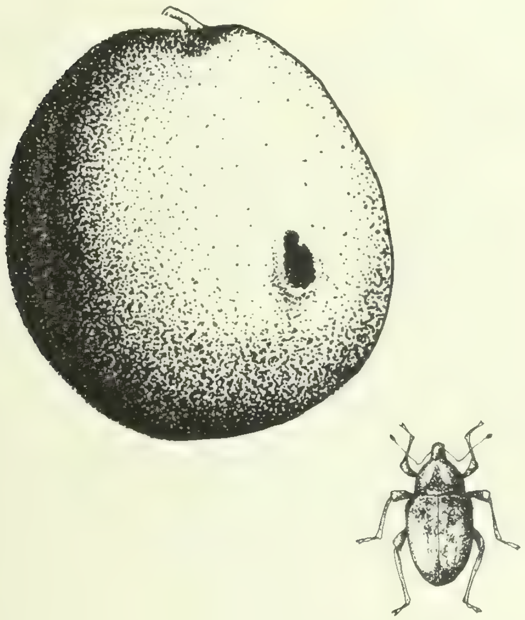
Injury

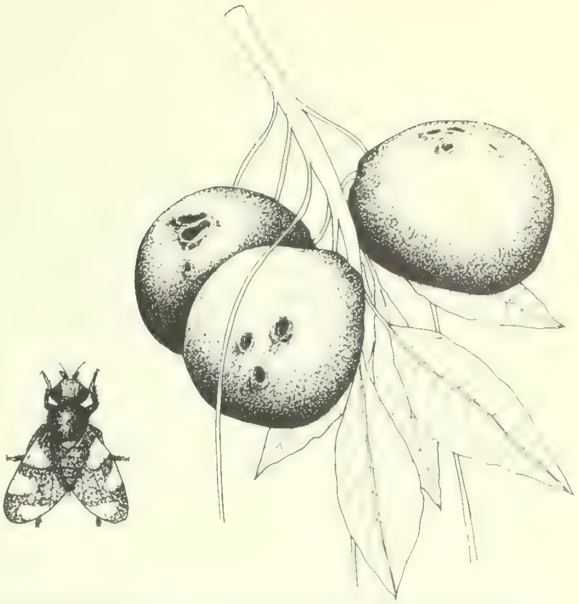
The adult female curculio lays eggs in young nuts in May, June, and July. The larvae bore into the developing nuts and cause great losses during the so-called "June drop" of walnuts. Walnut curculio larvae also cause the meager filling of walnuts that remain on the tree. A small exit hole in the side of a fallen nut is evidence that walnut curculio larvae have been present.

Walnut curculio has caused losses of 60 percent or more of the nut crop.

Control

Consult your local service forester or county extension agent for recommended chemical control. If you have only a few trees, immediately pick up and discard any immature nuts that fall during the growing season.





WALNUT HUSK MAGGOT,

RHAGOLETIS SUAVIS (LOEW) AND

WALNUT HUSK FLY,

RHAGOLETIS COMPLETA CRESSON

Description

The walnut husk fly and the walnut husk maggot both occur commonly throughout central United States.

The walnut husk fly and the husk maggot look alike. They are light brown in color and have two transparent wings with dark cross bars. They are smaller than the house fly. The larvae of both species are legless and pale yellow in color. Full grown larvae are up to 1/2 inch long.

Injury

The walnut husk fly and the walnut husk maggot breed and lay eggs in the husks of nearly mature walnut fruits in early autumn. The larvae burrow into and feed on the husk, producing black, slimy husks that stain and stick to the shell. The maggots can sometimes be seen crawling in the husks.

Husk maggots and husk flies do not penetrate into the nut, so the taste and color of the nutmeat are not affected. However, the slimy nature of the husks reduces their value to commercial nutmeat producers because the husk is difficult to remove. The infested husks also make the nuts unattractive and undesirable to the private walnut grower.

Control

Pick up and remove infested walnuts from the plantation as soon as possible after they fall from the trees. Contact your county extension agent for recommended controls.

WALNUT SHOOT MOTH,

ACROBASIS DEMOTELLA GROTE

Description

The walnut shoot moth is closely related to the pecan leaf casebearer, also an insect pest on black walnut. They are nearly identical in appearance but habits differ and serve to differentiate the two species.

Larvae of the walnut shoot moth are drab, olive-green with a black head capsule. They reach a length up to 3/4 inch. Adult moths are gray-brown with a small white patch on each front wing.

Newly hatched larvae overwinter in protective cases near the base of the terminal bud. In early spring each larva leaves its overwintering case and bores into the still unexpanded bud. Evidence of attack is indicated by a small pile of excrement and webbing deposited near the entrance hole.

Injury

Many terminal and lateral buds are killed, causing multiple forks and crooks in the main stem. If the attacked bud is not killed immediately, the stem of the expanding leaf is usually hollowed out and subject to breakage during high winds.

Control

Contact your county extension agent for recommended controls.

FOLIAGE OR LEAF SPOT DISEASES

Leaf spot diseases commonly occur on black walnut and other kinds of trees. They are caused by species of fungi that produce yellow, brown, or black spots on the leaves. Defoliation usually follows as the disease progresses. Foliage diseases are considered to be less serious than other types of diseases in black walnut because defoliation normally occurs late in the growing season. However, defoliation reduces growth and resistance to other stress factors.

DOWNY LEAFSPOT,

MICROSTROMA JUGLANDIS (BERANG.) SAC.

Description

Downy leafspot, also known as white mold, is characterized by small, white fuzzy areas on the lower surface of walnut leaves and pale yellow spots on the upper surface. The white fuzzy areas often fuse together so that almost the entire lower leaf surface may appear to be covered with a white powder.

Injury

The disease is of little significance because it does not kill the leaves or cause defoliation.

Control

No control is recommended.

POWDERY MILDEW,

MICROSPHAERA ALNI DC. EX WINT.

Description

Powdery mildew is a common disease on many plants and is caused by many different, closely related species of fungi.

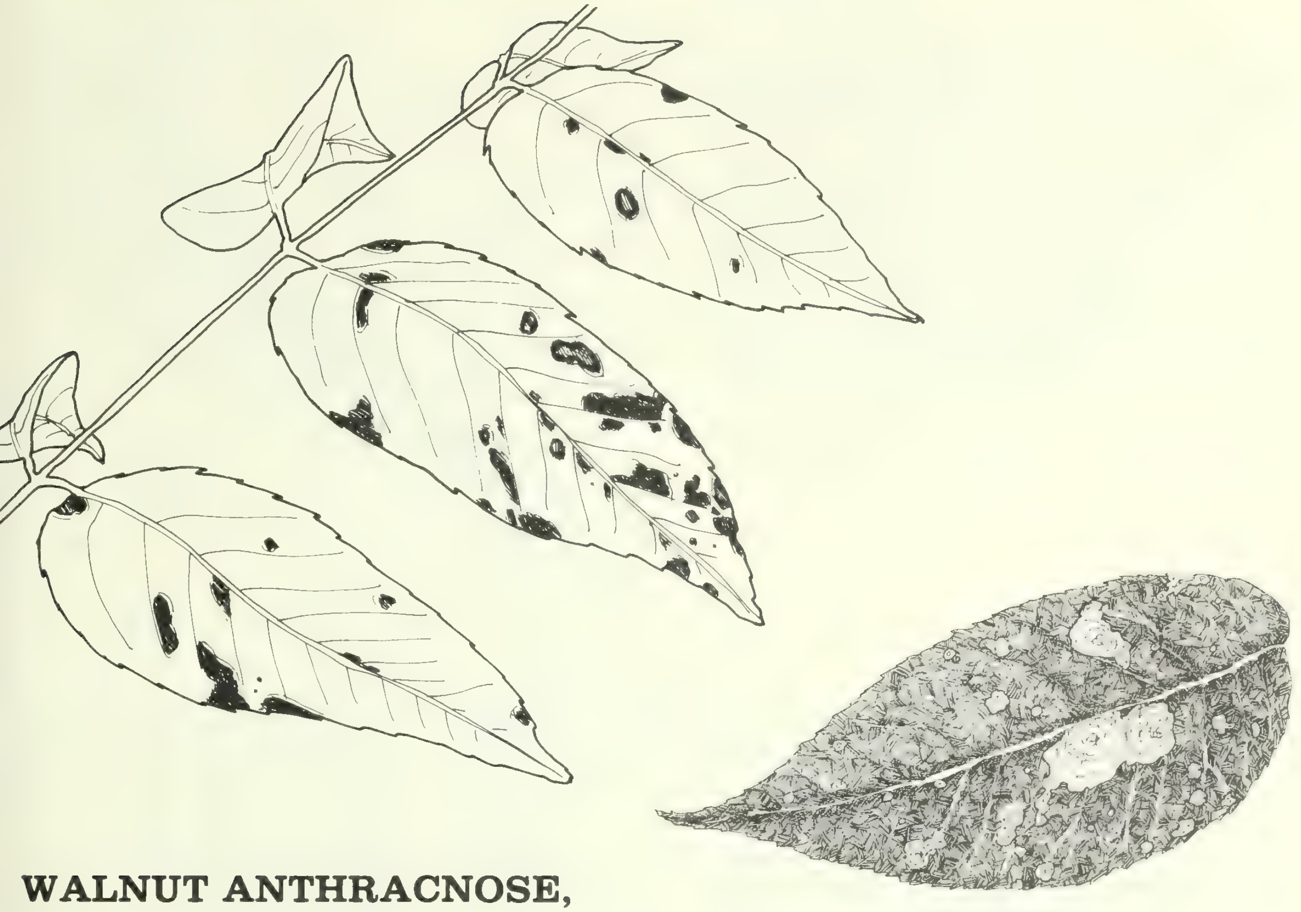
The fungus attacks leaves, buds, and young shoots covering diseased parts with a white powdery-looking mass of spores. The disease develops best in warm weather and humidity.

Injury

Heavily diseased leaves may shrivel up and turn brown. However, its occurrence on black walnut is rare.

Control

No control is recommended.



WALNUT ANTHRACNOSE,

GNOMONIA LEPTOSTYLA
(FR.) CES. & DE NOT.

Description

Walnut anthracnose is the most common leaf spot disease of black walnut and occurs wherever black walnut is grown.

The fungus causes small dark brown to black circular spots up to 1/2 inch in diameter on the leaves. These spots are usually bordered with yellow. Wet spring weather is ideal for the development of the disease, although symptoms may not become visible until June or July.

Injury

By mid-August leaves on trees infected with walnut anthracnose begin to turn yellow and drop. The growth rate of mildly to heavily infected trees is reduced. Heavily infected trees may be completely defoliated. Trees are not killed by the disease unless they are under stress from other causes. Anthracnose may also affect the quality of the nuts.

Control

Contact your service forester or county extension agent for recommended control. Fertilization with nitrogen may help reduce the harmful effects of this disease.

TARGET LEAFSPOT,

CRISTULARIELLA PYRAMIDALIS
WAT. & MARSH.

Description

Target leafspot, also known as bull's eye or zonate leafspot, is a recently discovered disease on black walnut. So far it has been reported on black walnut only in Illinois and Ohio.

The disease causes characteristic circular spots on the foliage with dark brown concentric rings inside each spot. These spots strongly resemble small targets, hence the name.

Injury

The disease progresses rapidly in black walnut. The leaf spots fuse together, causing an entire leaf to curl up, turn brown, and fall from the tree. Symptoms first appear early in August. Within only a few weeks the entire tree may be defoliated.

The disease causes premature defoliation, thus reducing the tree's growth, vigor, and resistance to other stress factors.

Control

No control has yet been developed. Fertilization with nitrogen should help minimize some of the harmful effects.

CANKER DISEASES

Cankers are defined as localized regions of dead plant tissue, or necrosis, in the bark of stems or branches of trees. Several different species of fungi cause cankers. Some cankers develop slowly over a period of several years whereas others grow rapidly once a tree has been infected. Cankers often completely girdle the stem, killing the tree. They are serious diseases and difficult to control.

FUSARIUM CANKERS,

FUSARIUM SP.

Description

Several species of *Fusarium* are known to cause cankers in black walnut in the Midwest and North Carolina. Trees in other States are also probably affected by the canker.

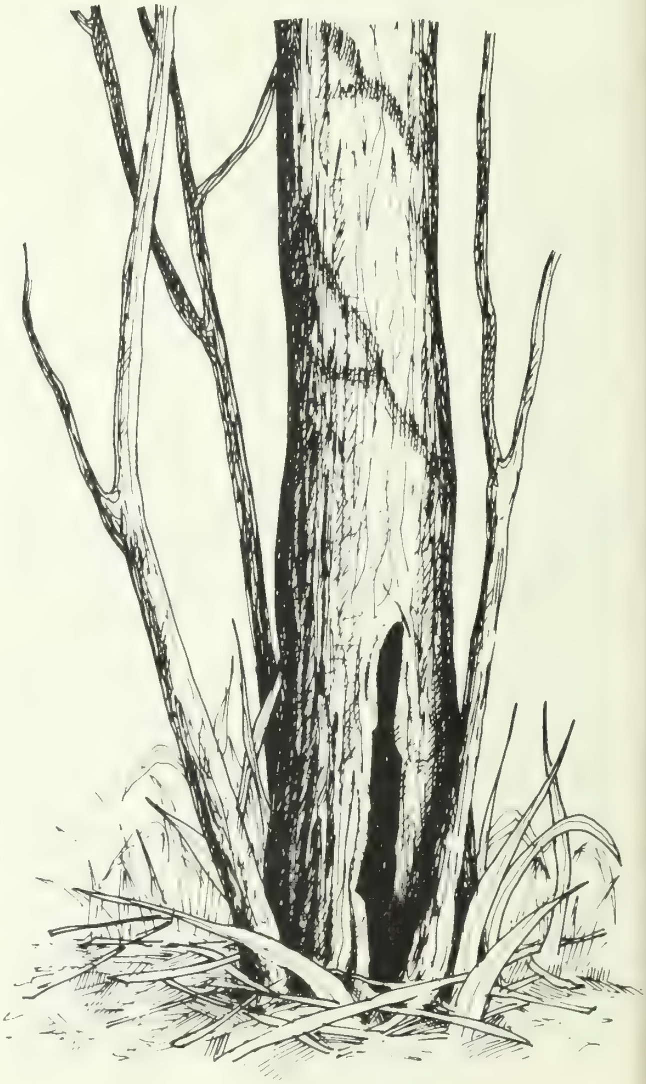
Elongate cankers of various lengths usually occur on the lower portions of the main stems of young trees, near the ground line. However, cankers may also occur higher on the stem or on branches in the lower crown of young trees. Cankers first appear as breaks in the bark or as expanding sunken areas. Darkly stained, diseased wood can be found beneath the bark. An affected tree often produces sprouts near the canker or at the base of the stem. Sometimes tiny pinholes caused by an ambrosia beetle can be found within the cankered area.

Injury

Affected trees show cankered, stained areas on the stems. An otherwise normal-looking tree that is producing many basal sprouts is commonly cankered. The primary injuries caused are wilting of leaves and dieback of the top. When the top has died, a sprout may take over and replace the lost tree, but several years of growth are lost.

Control

Cut and remove diseased trees from the plantation. Prune dormant trees and burn or remove pruning debris from the area.



PERENNIAL TARGET CANKER,

NECTRIA GALLIGENA BRESS.

Description

Perennial target canker, also known as Nectria canker, occurs on black walnut throughout its range, but seems to be more common in the Northeast and the southern Appalachians.

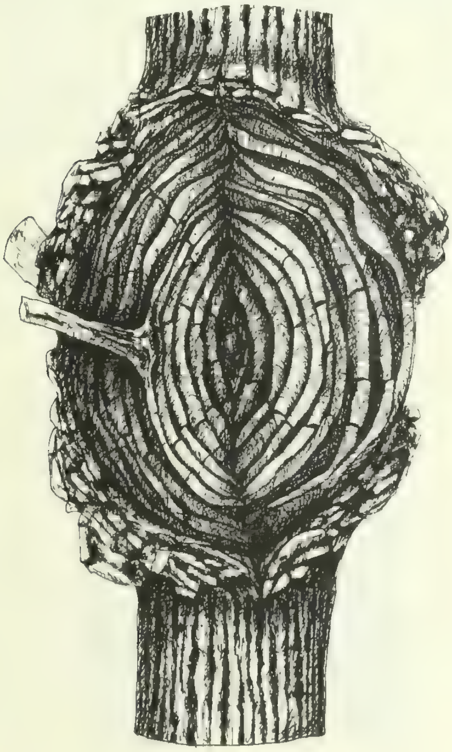
Old cankers are easily recognized because of their typical target shape, caused by rings, each of which represents a year's growth of callous tissue around the infected area. Young cankers are not as easily recognized because overgrown callous tissue may hide the affected area. Tiny, red fruiting bodies of the Nectria fungus may be present around the diseased area.

Injury

Cankers usually occur on the main stem of the tree, often at a point where a branch broke off and left an open wound. Nectria canker results in defects in the wood, stunting of growth, or death (if the canker becomes large enough to girdle the stem). Trees may also break at canker locations during high winds.

Control

Cut infected trees and remove from the area, including other tree species that may also be affected: yellow birch, sassafras, paper birch, northern red oak, red maple, beech, and bigtooth aspen.



MAMMAL DAMAGE

Deer, squirrels, mice, rabbits, and beaver are the most common and destructive. Types of damage caused include nipped buds, gnawed or shredded bark, girdled stems, reduced nut crop, and stolen nuts that had been planted for trees. Loss of growth, severe forking, or death are the final results of mammal damage.

DEER DAMAGE

Description and Injury

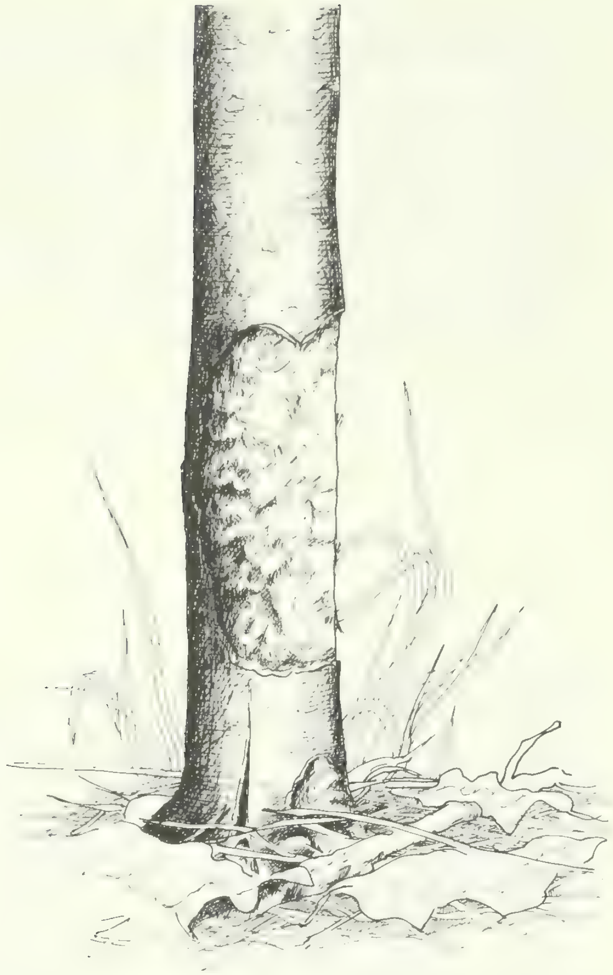
Buck deer rub against young black walnut trees in the fall to remove the velvet from their antlers, often shredding the bark and leaving it hanging in strips. Larger trees, more resistant to bending, are usually not affected.

Deer may also nip the buds of smaller trees, causing forking of the main stem. In areas of high deer populations, tree growth may be stunted because terminal buds are eaten by deer every year.

Control

An effective, but expensive, means of preventing deer damage is to erect a tall fence around the entire plantation.

Another suggested but not proven means of control is to hang cloth bags containing tankage (dead animal residues, obtainable from slaughter houses) on every second or third tree around the periphery of the plantation.



RODENT DAMAGE

Description and Injury

Mice, rabbits, and other small mammals gnaw on the stems of young trees, usually during winter, and remove patches of bark. Teeth marks are usually visible at the base of the tree.

Squirrels are a common problem in black walnut. Walnuts are a favorite food of squirrels, which feed on green nuts still hanging on the tree or mature nuts after they have fallen. Squirrels also dig up planted walnut seeds, sometimes destroying entire plantations seeded directly with nuts.

Control

Wire screening around the base of young walnut trees will prevent small rodents from eating the bark.

Commercial animal repellents seem to have little or no effect on squirrels. The most effective control known to date is to place *fresh* cow manure on top of each newly planted nut.

OTHER

This category includes all other factors that may damage black walnut, e.g., frost, birdpeck and other bird damage, decay, flooding, herbicides, mechanical damage, unexplained dieback, or any other type of damage for which the exact cause is not known. Generally, there are few control measures. The best solution is to prevent initial damage to the trees by following recommendations for site selection and care of the trees.

BIRDPECK

Description

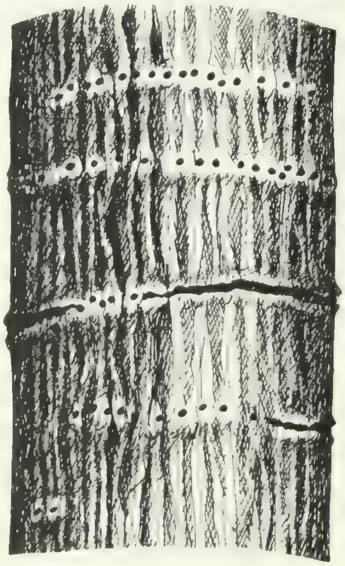
Birdpeck is caused by the yellow-breasted sapsucker, *Sphyrapicus varius.* Damage to black walnut normally occurs during late winter or early spring when sap is flowing on warm days. The sapsucker feeds directly on the sap and not on insects. It may drill test holes into several different trees. Once a favorite tree is found, the bird usually returns to that tree often until it may be nearly girdled with peck holes.

Injury

Holes made by the sapsucker normally heal over quickly but they cause defects and stain in the wood, reducing the value and quality of products made from it.

Control

No control measures are known at this time.



BIRD DAMAGE

Description and Injury

Breakage of the main stem of young black walnut trees by perching birds has occasionally been reported. Red-wing blackbirds and owls are the birds most commonly seen in association with this type of damage.

The main stem of the tree or branches are broken but usually remain hanging on the tree.

Control

Erecting several tall poles at various places within the plantation may provide the birds with more desirable perches than fragile young trees.

DECAY

Description and Injury

Decay here refers to any soft, spongy, unsound, hollow, or open area in the bark of a tree that appears to be rotting away. This part of the tree is dead and the decay is caused by fungi that live on dead wood. A hollow trunk or one that is decaying on the inside is not always evident from the outside.

Not all stain-producing fungi cause decay, but stain itself reduces the value of the wood.

Any mechanical- or fire-caused damage to a live tree leaves an open wound, that may be invaded by wood-decay or wood-staining organisms.

Control

Avoid any injury to black walnut trees that may allow the entrance of decay organisms. Prune trees properly and only during late fall and winter, when the trees are dormant and decay fungi are least prevalent.

DIEBACK

Description and Injury

Dieback refers to the dead branches or tips of branches in the crowns of otherwise apparently healthy trees. The cause is usually difficult to determine and may be due to poor drainage, herbicide damage, poor site, root rot, climate, flooding, disease, insects, or some unknown factor.

Control

Plant healthy trees on proper sites, provide adequate weed control, and maintain the vigor of trees by pruning dead or diseased branches and thinning out undesirable trees in crowded plantations.

FROST DAMAGE

Description and Injury

Frost damage in black walnut occurs when warm spells in spring, which cause buds to break, are followed by late frosts. This results in wilting, blackening, and death of the already expanded leaves and death to buds that were just beginning to break. The trees recover and put out new leaves, but forks and crooks often occur in young trees. Trees and plantations located in frost pockets are particularly susceptible. As trees grow taller they become less susceptible to occasional light frosts. Young trees may be stunted by repeated frost damage and tend to be bushy with many forks.

Control

Do not plant walnut trees in known frost pockets.

SOME HELPFUL PUBLICATIONS

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GLOSSARY

Canker. — dead area in plant tissues usually caused by disease.

Fruiting body. — the spore-bearing organ of a fungus (conk).

Gall. — swelling of plant tissue in reaction to feeding by insects or mites; usually found on leaves but may also occur on other plant parts.

Girdle. — damage that completely encircles the main stem of a tree, killing all wood above the damaged point; may be caused by cankers, bird-peck, rodent feeding, etc.

Larva. — immature, wingless stage of insects such as moths, beetles, and flies between the egg and adult stage; also sometimes known as caterpillar or "worm" (plural = larvae).

Lateral bud.— any bud on a tree other than the end one on the main stem or side branch.

Necrosis. — dead plant tissue, usually stained brown or black, surrounded by living tissue.

Nymph. — immature wingless stage of such insects as grasshoppers, cicadas, and lacebugs.

Ovipositor. — egg-laying organ or structure often extending from the posterior abdomen of female insects.

Photosynthesis. — food manufacturing process in all green plants using water, carbon dioxide, and sunlight.

Terminal bud. — usually the end bud on the leader or main stem of a tree, but may also refer to the end bud on each side branch.

Weber, Barbara C., Robert L. Anderson, and William H. Hoffard. 1980. How to diagnose black walnut damage. U.S. Department of Agriculture Forest Service, General Technical Report NC-57, 20 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Presents a key to common insect, disease, animal, and other damages to black walnut. Also includes illustrations of many of the damage types and descriptions of the causal agents. Preventive or control recommendations are made where appropriate.

KEY WORDS: *juglans nigra*, causal agents, illustrations, descriptions, control recommendations.

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NERGY&WOOD from intensively cultured plantations: research and development program

North Central Forest Experiment Station
Forest Service, U.S. Department of Agriculture

North Central Forest Experiment Station
Forest Service - U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
1980

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ENERGY&WOOD

from intensively cultured plantations: research and development program

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The first small plot experiments were established in 197 to test the growth of various Populus *clones and th effect of spacing on yield.*

BACKGROUND

The Maximum Yield Work Unit was established in 1971, by the North Central Forest Experiment Station in response to concerns expressed by both industrial foresters and researchers. Industrial foresters realized that new systems for growing more fiber on less land must be explored because of escalating fiber demand, increasing demand for recreation and non-forest uses of forest land, rising land prices and tax rates, and increasing harvest and transportation costs.

Forestry researchers realized that much basic genetic, physiological, and cultural knowledge could be applied if environmental conditions for growing trees could be more closely controlled as in agriculture. Research was begun to select promising species, establish intensively cultured plots, explore new harvesting methods, evaluate pulping qualities of the fiber, and assess the economic viability of this system. This program used a systems approach, with researchers from many different disciplines working together.

In 1976, the program was expanded to incorporate both developmental and basic research, active cooperation with industries, and the collaboration o scientists from different disciplines in a systems approach. The research team now includes silviculturists, physiologists, an ecologist, geneticists, a soi scientist, hydrologist, a wood technologist, a pathologist, an entomologist, an engineer, and an economist

Supplemental funding from the Department of Energy since 1977 has enabled researchers to accelerat progress in several problem areas, with emphasis placed on the development of methods to plant tree and ensure their early survival. Establishment is th most critical problem in the short-rotation-intensive culture (SRIC) system because larger research studies or large-scale industrial plantations cannot b established until the technology to successfully plan hardwood stands has been developed. Although practices for planting softwoods were developed long ago no system for consistently establishing plantations o hardwood forest trees in the upper Midwest has bee developed (except for the shelterbelt plantings of th northern Plains). The problems in large-scale planting operations are often different from those normally encountered in small plot experiments, and th additional funds have enabled researchers to provid nformation to help industry establish larger pilot-ized plantations.

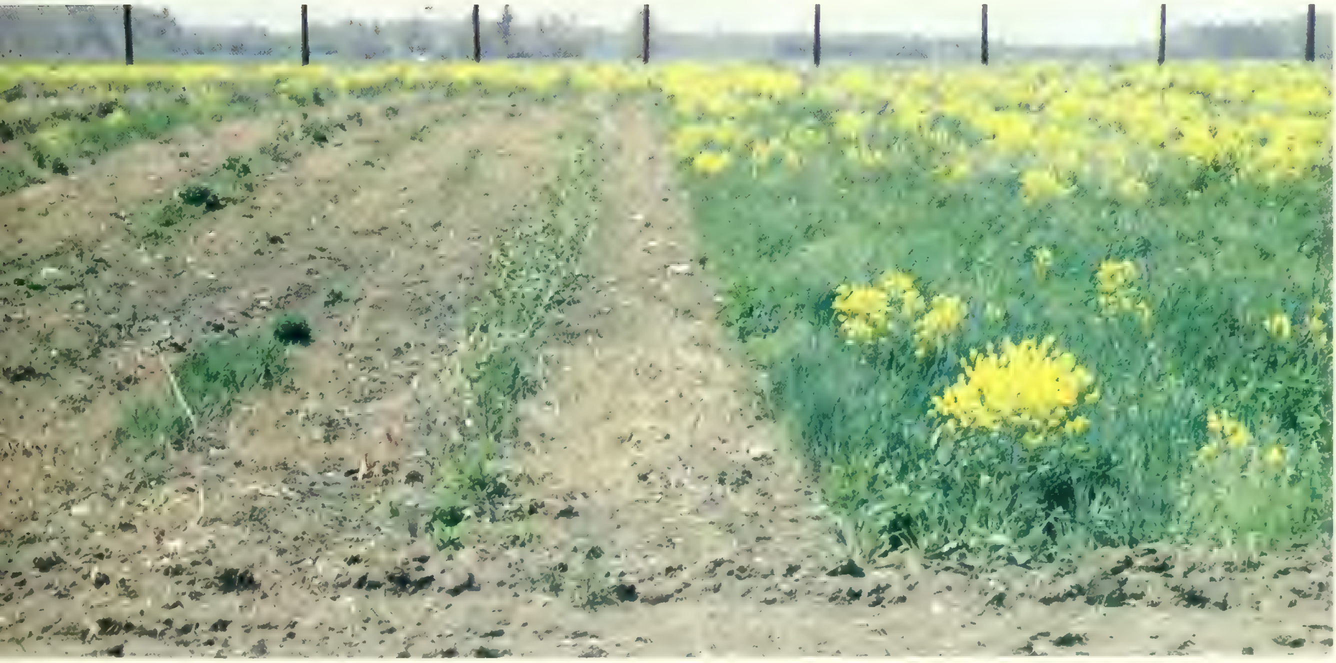
Iore than 10 acres a year of intensively cultured lantations are being established at the Harshaw xperimental Farm near Rhinelander, Wisconsin. Emhasis is on developing cultural practices and mechanzed equipment suitable for operational plantation anagement.

The USDA Forest Service's Maximum Yield of Wood and Energy from Intensively Cultured Plantations Research and Development Program includes two Research Work Units as well as scientists from other Research Work Units within the North Central Forest Experiment Station. Research problems, objectives, and results will be presented separately in this report for each problem area, although this does not accurately represent the overlap and interaction between problem areas due to the complex set of factors that determine biomass yield.

Briefly, the SRIC concept is that plantation biomass yields can be greatly increased by using genetically superior planting material and optimizing field environmental conditions. Generally, hardwoods have been tested more thoroughly for intensive culture systems because of their rapid juvenile growth and their ability to sprout from the stump after they are harvested, thus eliminating the need to replant the trees.

The establishment of intensive culture plantations with most species in any region of the United States will likely include essentially the same kinds of operations, although the precise nature of these operations will vary greatly by species and site. Many of these concepts are more typically termed "agricultural" rather than "silvicultural" in nature.

One of the most critical problems in establishing the short-rotation-intensive-culture system is weed control. Weeds are a serious competitor during the first 2 years, and research in weed control methods has recently been expanded.



First, the land must be cleared and plowed to eliminate other plants and to make the site suitable for planting and cultural equipment (i.e., abandoned farm land is well suited). Seedlings or cuttings are planted with mechanical planting equipment at varied distances from a few centimeters to several meters within the rows that are from 1 to several meters apart. The first growing season is critical to the survival of the small trees, and plantations must be kept free of weeds either by cultivating, planting a cover crop between the rows, applying an herbicide, or other means. Each growing season the trees are provided optimal amounts of nutrients and water by fertilizing and irrigating. Diseases and insect pest are also controlled.

After 6 to 10 years, at a time when the trees reac near-optimal biological growth, the trees could b harvested using specially-designed harvesters. Th wood will likely be chipped and used for energy, pul reconstituted wood products, feed, chemicals, or an combination of these products. In the spring follow ing harvest, several new stems will sprout from eac cut stump (coppice), and these will become the nex crop of trees.

Irrigation is one of the cultural practices being studied this research program. More precise information abo the quantity and timing of irrigation is still needed.

SELECTION OF PROMISING SPECIES

hese plots were established in 1974 to test the perform-
nce of different Populus *clones. Note the differences in*
rowth rate of these clones after 3 years under similar
ntensive culture conditions.

Research Problem

The characteristics of high-yielding trees for inten-
ive culture are significantly different than those for
onventional forestry. Selected species must be bio-
ogically efficient to take full advantage of the optim-
zed conditions of intensive culture.

Research Objectives

Promising species and clones must be screened for
wide range of biological and physical properties.
nitial tests include growth rate, response to different
pacings, response to water and nutrient man-
gement, sprouting ability, insect and disease re-
istance, wood quality, and adaptation to regional
limatic conditions. As results from physiological
tudies of crown architecture, photosynthesis, and
ranslocation of photosynthetic products are ob-
ained, they will be included in genetic selection and
reeding programs.

Research Results

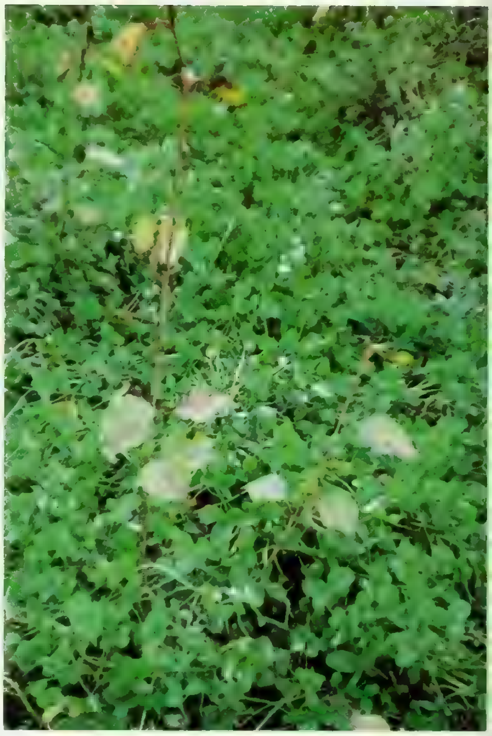
The genus *Populus* (poplars and cottonwoods) was selected for the early experiments because of its rapid juvenile growth, ease of hybridization, vegetative propagation, and the vast amount of information already known about its growing requirements. In 1971, 30 *Populus* hybrid clones were tested in field plots at Rhinelander, Wisconsin, and Ames, Iowa. Fourteen of these have been selected for further testing under various intensive culture techniques. Other species tested included jack pine, (*Pinus banksiana*), larch (*Larix laricina*), alder (*Alnus*), and green ash (*Fraxinus pennsylvanica*).

Rapid laboratory screening tests have been conducted using physiological and morphological characteristics, such as net photosynthesis rate, production of enzymes controlling nitrogen uptake and metabolism, branch angle, and leaf orientation on branches.

Controlled-environment chamber experiments were also completed for 25 Populus clones using 3 different combinations of growth period and temperature. After comparing total biomass, leaf weight, stem weight, height, and leaf number at 8 weeks, 14 clones were recommended for field testing.

STAND ESTABLISHMENT METHODS

Weed competition is one of the most serious problems in establishing hardwoods for intensive culture. In field experiments, the herbicide "Roundup" was found to keep stands almost free of weeds.



Planting low lying leguminous cover crops may be an effective way of simultaneously providing soil nitrogen and controlling weeds. White Dutch clover shown here prevents the growth of taller weeds that might otherwise shade and compete with the hybrid poplar cuttings, but is also competitive with the trees.

Research Problem

The survival of trees during the critical first 2 years is primarily determined by vigor of the planting stock; adequacy of site preparation, fertilization, and irrigation; and control of competing weeds. Because early site occupation is desired for intensive silviculture systems, high survival of planted trees is important. Stand establishment techniques have not been well developed for hardwood plantations, although application of agronomic and horticultural methods offer promise.

Research Objectives

It is expected that plantation establishment methods for *Populus* clones will be developed during the next 5 years to attain a survival rate of 90 percent. Methods for site preparation; mechanical, biological, and chemical weed control; and mechanization of cultural operations will be studied. In particular, conventional farming techniques will be tested. Alternative vegetative propagation systems will be studied, including methods for collecting and storing cuttings, methods for obtaining plants from greenhouse stock plants, methods for stimulating the rooting of clones that are difficult to root, and possibly systems for establishing cuttings in containers.

Research Results

Studies began in 1978 to test the effectiveness of 245 combinations of methods of weed control in both spring and summer plantings were evaluated after the first year. The best site preparation methods were chisel plowing or a combination of moldboard plowing to 9- to 10-inch depths followed by disking and spike-tooth harrowing. Crownvetch and birdsfoot

Weeds may be controlled by mowing, a method that is widely used in orchards.

trefoil, both leguminous nitrogen-fixing plants, were the most effective cover crops for stimulating tree growth during the first year, but were not effective when evaluated the second year. "Linuron" and "Roundup" herbicides were the most effective herbicides when no other weed control method was used. A combination of a crownvetch cover crop together with herbicide "Treflan" was slightly better than any other weed control treatment.

One year of data is by no means conclusive, and the above-average rainfall during the growing season may have produced different results than a similar experiment in a drier year. However, this study provides preliminary information regarding promising site preparation and weed control methods that should be tested in larger plantings.

The optimal propagation method may vary with the time of planting. In this study, soaked and unsoaked hardwood cuttings had the best height growth and survival for all planting dates. Rooted hardwood cuttings in "Tubepak" containers provided no advantage in either survival or height growth. Bare rooted tip cuttings performed poorly for all planting dates.

Some of the fastest-growing *Populus* clones, in particular, *P. alba L.* x *P. grandidentata* Michx. hybrid (Crandon), are difficult to establish vegetatively—less than 50 percent of the cuttings rooted using normal greenhouse practices. However, rooting greenwood tip cuttings in greenhouse flats at temperatures of 76° to 85°F provided 70 to 100 percent rooting success, faster rates of root elongation, and less mortality from fungal and bacterial infections. Hormone treatments increased rooting success and number of roots per cutting, but hormone concentration was less important than temperature.

Containerized Populus *cuttings are grown in the greenhouse in preparation for planting. The survival rate of these rooted cuttings will be compared to that of unrooted cuttings to determine the most effective methods of stand establishment.*

New greenhouse methods such as hydroponics are being tested for mass production of rooted greenwood cuttings. This method may be more economical for establishing cutting orchards because it uses less greenhouse space than containerized stock.

FIBER AND ENERGY YIELDS IN RESPONSE TO SPACING AND HARVEST CYCLES

Trees planted at close spacings will quickly occupy the entire site. After 6 years, essentially no sunlight will reach the ground in this stand, which was planted at 0.6 m x 0.6 m spacing.

Research Problem

One of the keys to maximizing fiber and energy production in forest stands is to optimize cultural practices— the spacing and rotation age for the selected species and clones. In particular, information is needed on the efficiency of capturing solar energy by plants and the energy relations in intensively cultured plantations.

It is known that closely spaced stands (1 × 1 m or less) fully occupy the site within a few years; therefore, essentially all the sunlight is intercepted by the leaves before it reached the ground. Closely spaced stands also attain maximum mean annual production early in the rotation, but the competition between trees begins to reduce the annual biomass production per tree. In addition, closely spaced stands are more expensive to establish and it is doubtful that these additional costs can be recouped through higher yields. Because the mean annual production is closely related to the stand's leaf area index (leaf surface area per unit land area), it appears that early optimization of leaf area may increase yields, much as cultural systems to optimize leaf area index in agriculture have been successful.

Research Objectives

Preliminary research on small plots to determine the effect of spacing and rotation age on yields has almost been completed, and researchers are currently evaluating the most promising spacings and rotation ages on yields of larger field plots. From the results of specific studies they will establish mathematical relations between total tree dry weight and easily measured variables such as diameter and height, determine effects of spacing on dry weight distribution among tree components, and determine leaf biomass and leaf area index with respect to various yields. The optimal combinations of spacing and rotation will be studied for the maximization of fiber and energy production in stands of *Populus*, alder (*Alnus glutinosa*), jack pine, and larch. The distribution of major nutrients within the stands will be studied and effects of frequent harvesting on nutrient budgets will be determined.

An integral part of biomass production studies is determining the efficiency of solar energy utilization by plants. This energy data is particularly needed for evaluating systems in which tree plantations would be utilized as an energy source. By comparing the heat of combustion of harvested biomass to the energy requirements for intensive culture, the net energy gains will be assessed.

Research Results

Early field tests of closely-spaced *Populus* 'Tristis' hybrids showed that total aboveground biomass yields could exceed 20 dry tons/ha/year for 4-year-old rees grown under intensive culture. Tree growth nd competition information from these plots was hen used to model stand growth and project yields or 10- to 25-year rotations. The table below summaizes both the observed yields on small plots, and the rojected yields of stems and branches (Ek and awson 1976):

Stem-Branch Biomass Yield

Item	Spacing			
	0.23 m	**0.30 m**	**0.61 m**	**1.22 m**
	-----------------*t/ha/yr*-----------------			
Actual yields:				
4 years	11.3	13.0	7.5	—
Projected yields:				
10 years	17.0	16.5	16.0	15.5
15 years	—	—	—	29.0
20 years	—	—	—	36.0

Field studies have shown that 1.0 m spacings will ave the same annual yields as 0.23 m spacings after to 6 years. Therefore, field tests of selected clones ave now been established to test spacings up to 2.0 n and the effects of various cultural practices on hose spacings.

Although hardwoods have been used most comnonly in intensive culture studies, yields of oftwoods may exceed those of hardwoods on certain ites. Hardwoods are site-demanding, and the estabishment of hardwoods on poor sites may be unecoiomical because of heavy fertilizer and weed control equirements. Intensively cultured plantations of 7-ear-old tamarack (*Larix laricina*) were found to proluce 4.3 to 5.2 tons/ha annually, when planted at lose spacings, fertilized, and irrigated. Under simiar conditions, 7-year-old jack pine produced higher ields, ranging from 6.8 to 8.1 tons/ha annually. Opional spacings will be determined by the expected otation age; for example, the maximum mean anual increment for the 0.23 m × 0.23 m spacings ccurred at age 6 for tamarack and age 5 for jack pine. s spacing increases, the corresponding rotation age ncreases also.

The use of such intensive culture methods as fertilzation, irrigation, and cultivation appears to be an fficient use of energy. The ratio of net energy gain to otal energy utilized was calculated to be 4.3 for *Populus* and 4.7 for jack pine, with a net energy content of 306 MBtu/ha for *Populus* and 236 MBtu/ha for jack pine. When comparing the net energy ratios for intensive culture systems and naturally regenerated forests, it appears that net energy returns are linearly and positively related with the energy invested in the system. Although net energy ratios of up to 157:1 have been reported for natural forests, the energy produced annually per acre by these stands is very low. To meet future fiber and energy demands from forests, more intensive systems will have to be used, and it appears that these systems will be efficient producers of energy.

Many hardwoods will coppice or sprout from the stump after cutting thus eliminating establishment costs for the next rotation. The vigor of coppice growth will differ greatly by species and clone and must be determined in field tests.

YIELD RESPONSE TO NUTRIENT AND MOISTURE REGIMES

A traveling irrigation system is used to provide water fo the large field experiments. During operation, a wate turbine powered winch advances the unit along a cabl anchored at one end of the irrigation lane. The unit i drawn by tractor back to the starting point at th beginning of each day that irrigation is required.

Research Problem

Conventional silvicultural practices have historically provided less than optimum nutrient and water supplies to trees, and therefore tree growth has not approached the biological potential of the species. Traditional practices reduce the number of trees on a site to allocate the fixed supply of water and nutrients to fewer trees. With SRIC systems the number of trees (spacing) is fixed at the time of planting and the problem is to determine the quantity of water and fertilizer necessary for maximum yield. Related problems are to determine the timing of fertilizer and water application and the extent to which nitrogen-fixing plants may be introduced into intensive culture plantations to reduce costly nitrogen fertilization.

Research Objectives

Gross plant nutrient and moisture requirements are known for the genera under consideration for intensive culture, but the specific requirements for promising species and/or clones are not known. Th growth responses with regard to fertilizer applicatio rate, formulation, placement, and time all must b determined experimentally. Furthermore, the interaction of irrigation and fertilization in affecting plan growth will be studied. Research in growth-room greenhouse, and field studies will be conducted t identify the soil-water potential and nutrient level of the plant and soil for maximum plant growth fo selected clones. Also, changes in physical and chemical soil properties and ground water quality will b identified.

Research Results

A Continuous Function Design was used in field experiments, with a moisture gradient superimposed t right angles upon a fertilization gradient. The ffects of the independent variables (water and nitroen level) and all the combinations of these two varibles on the growth of hybrid poplar were thus tested n ¼-acre plot. The water was provided by a trickle rrigation system and the fertilizer, ammonium nirate, was applied by hand. Measurements after the econd year show that up to 2 inches of irrigation per eek considerably increased height growth, whereas dditional amounts of irrigation (more than 3 inches er week) inhibited height growth. Fertilization with 00 lbs/acre/year nitrogen as ammonium nitrate inreased height growth as much as 30 percent. Addiional amounts of nitrogen decreased height growth. smaller plot with an irrigation gradient and ncreasing percentages of nitrogen-fixing *Alnus gluinosa* planted among the *Populus* showed that *Popuus* height growth increased about the same when ixed with a large proportion of *Alnus* as when ferilizer was applied. This has significant implications or reducing fertilization costs in intensive culture ystems.

trickle irrigation system is used for precise application f water in irrigation studies. Microtubes discharge ater at 4-foot intervals along the ½-inch plastic pipe. he nutrient gradient was established by hand applicaion of fertilizer.

EFFECT OF CROWN ARCHITECTURE AND CANOPY ON YIELD

Light interception is related to both the number of leaves per tree and the leaf area per tree. Leaves of selected Populus *clones grown under SRIC may exceed 30 cm in length, and provide a large surface area for light interception.*

Problem

The amount of sunlight that leaves intercept is greatly dependent on the arrangement of leaves on the branches (crown architecture) and the density of leaves within the stand canopy. This captured light, in turn, directly affects the amount of photosynthetic activity and total biomass production. When the most advantageous leaf arrangement on branches is known, trees with these characteristics can be selected for clonal testing under SRIC.

Total biomass production in both agricultural and silvicultural systems is closely related to total leaf area of the stand. Two of the major limitations to productivity of plants are the length of time required to obtain the optimum leaf area index and the ability to maintain that optimum leaf area. The low productivity of many forest stands is partly due to the lengthy period of time required to achieve optimum leaf area. A goal of SRIC forestry is to increase the effective leaf area earlier in the rotation and maintain it longer than more conventional forest systems.

The suitability of trees grown under SRIC for pulp production also depends partly on the distibution of biomass among tree components. Crown architecture will influence the percentage of biomass in branch and stem wood, and thus affect quality of yield for pulp and other wood products.

Research Objectives

The "ideal" tree for intensive culture will be further defined through studies that evaluate the effect of crown architecture and canopy density on yield. To identify these attributes, scientists will determine leaf development throughout the growing season, light interception by leaves within the stand, and affect of crown architecture on distribution of photosynthetic products within the tree. Studies will also address the affects of growth regulators on leaf production and the affect of spacing, cultural practices, and age on canopy characteristics.

Research Results

Distribution of the number of leaves per tree and the leaf area index was studied in a 5-year-old stand of *Populus* 'Tristis' grown under SRIC at 1.2 m spacing. Average leaf area index was 7.6, which is 1 to 5 times higher than reported natural stands of *Populus* in the same area. Trees contained an average of more than 6,600 leaves or 4,800 leaves per square meter. The percentage of leaf area on long shoots was 53 percent, compared to 10 to 20 percent on trees grown in native stands. Leaves on short shoots are produced early in the growing season and mature early. Long shoots produce leaves continually during the growing season, thus providing an advantage of continuous production of photosynthate throughout the summer.

During the first 3 years, leaf area per tree and number of leaves per tree for several *Populus* clones were not affected by planting densities from 0.2 to 1.4 meters. Thus, attainment of high leaf area indices and concomitant rapid growth depends greatly on the high density of trees in the early years of establishment. In SRIC forestry leaves are concentrated on a large number of individuals rather than a few as in more conventional forests.

Leaf area index describes the surface area available for photosynthesis in forest stands and is one of the best indicators of photosynthetic capacity. Automatic measurement of the surface area of each leaf using this instrument has greatly accelerated research in this area.

Observation of the vertical distribution of leaves within the canopy showed that about 25 percent of the leaf area produced on 3-year-old *Populus* 'Tristis' was on the terminal shoot. Because photosynthates produced by the terminal shoot leaves are directly translocated to the stem, greater proportions of leaves on the terminal shoot will no doubt increase stem biomass production. The lower branches of intensively cultured trees retain their leaves longer than those of conventionally cultured trees, which results in an even greater leaf surface area for light interception. This retention can most likely be attributed to the optimum growing conditions of intensively cultured trees.

Gross photosynthetic rates of Populus *are measured in the field using a* $^{14}CO_2$ *technique. Measurements of leaf conductance, leaf and air temperature, relative humidity, and photon flux density are made concomitantly to provide for the proper interpretation of photosynthetic rates.*

Problem

Photosynthates (mostly sugars) are produced in the leaves during photosynthesis and are then translocated to all other parts of the tree. These photosynthetic products may be used for maintaining plant processes (respiration) or for producing biomass. Therefore, the net biomass production is dependent on the rates of photosynthesis and respiration, as well as on the distribution of photosynthates among plant parts.

Numerous physiological variables have been identified through extensive agronomic research as important determinants of biomass production in crop plants, but the importance of most of these variables has not been determined for woody plants. When more information about the desirable characteristics of trees for SRIC systems is available, genetic tree improvement programs can incorporate these traits into selections.

Research Objectives

The relation between physiological variables and the quantity and quality of yield for selected trees

The CO_2 *compensation point of excised* Populus *leaves is measured in the laboratory. Such information about physiological responses may be used to preselect clones before expensive field screening is conducted.*

Populus *leaves are exposed to* $^{14}CO_2$ *in the field. Three days later, the whole tree will be harvested and the* $^{14}CO_2$ *activity will be measured in the leaves, branches, stem, and roots.*

grown under intensive culture will be studied. These variables will include rates of photosynthesis and respiration, photosynthetic efficiency, patterns of photosynthetic activity during the growing season, patterns of photosynthesis within the tree crown, and patterns of photosynthate distribution within the tree. Recommendations for selecting trees can then be based on the complex system of physiological variables know to affect yield.

The methodology for conducting physiological studies on trees in the field is not available, partly because of the size and complexity of trees. Therefore, considerable effort will be needed to develop field physiological research techniques for young intensively cultured trees.

Research Results

Field, greenhouse, growth chamber, and laboratory studies have been initiated to measure the rate of net photosynthesis, leaf conductance, and CO_2 compensation points of individual leaves at various positions within the canopy throughout the growing season. Concurrently, the translocation of photosynthates is measured by exposing groups of three fully-expanded contiguous leaves to $^{14}CO_2$. Trees are harvested after 72 hours and sampled for percentage of ^{14}C-activity in various tree components to determine the translocation of photosynthates produced during the exposure to $^{14}CO_2$. Laboratory experiments to confirm exposure and sampling methods have been completed, and as trees grow older and more complex it is expected that more sophisticated field sampling methods will be developed.

Field experiments with young *Populus* trees grown under SRIC have provided some preliminary results. The upper leaves translocate photosynthates upward for use in shoot development, the middle leaves translocate photosynthates both upward to the shoot and downward to the lower stem and roots, and the lower nonexpanding mature leaves translocate primarily downward to the lower stem and roots, where they are utilized for vascular and structural tissues. These results suggest that because mature leaves contribute mainly to stem wood production, it may be desirable to select for trees that retain mature leaves.

RAW MATERIAL QUALITY OF INTENSIVELY CULTURED TREES

Scanning electron micrograph of a tension wood fiber from short rotation intensively cultured Populus *tree. Surface dislocations (wrinkles) on the fiber affect subsequent paper strength properties (2000X).*

Problem

The value of biomass produced under SRIC systems depends primarily on the type of specific products for which it can be used. Because wood is such a versatile raw material, an integrated research program must consider the value of wood produced under intensive culture for a wide range of current products as well as those that may be demanded in the future.

Intensive culture practices influence physiological processes which in turn affect the anatomy, chemical composition, and physical properties of the raw material and therefore the usefulness of the material.

Research Objectives

The effect of such variables as plant material, spacing, fertilization, moisture regimes, and age on the quality of raw material will be determined. Tests will be made to measure the suitability of raw material produced by SRIC (including bark) for pulp and paper, particleboard, fiberboard, chemical feedstocks, energy, and animal feed. For the purposes of genetic selection and breeding programs, the most desirable raw material attributes for trees grown under intensive culture will be identified.

Research Results

The energy content of most woods is similar—hardwoods average 4,400 and softwoods average 5,000 kcal per kg of ovendry wood. The factors that contribute to differences in energy value of wood are the moisture content, density, and the ease of drying before conversion. Density will also affect transportation costs and may affect rates of conversion. Tests of juvenile *Populus* wood grown under SRIC have shown that moisture content and density are not significantly different from wood grown under conventional systems.

Wood quality may be important in indirect energy conversion processes and for the utilization of wood as liquid fuel and chemical feedstock. For example, lignin may hinder the conversion process, and appropriate plant selections could be made for genotypes with low lignin contents. When conversion processes and wood quality needs for these processes are better defined, research in this area will be more appropriate.

The primary concerns associated with the use of rapidly grown juvenile wood for pulp and paper are that high percentges of bark may be present in whole-tree chips and that juvenile wood has shorter fibers than mature wood, which can adversely affect pulp yields and paper strength.

Most anatomical characteristics vary greatly by species and clone and thus are important selection factors that affect utilization. Anatomical studies have generally shown higher percentages of spring wood and transition fibers in wood grown under SRIC; this fact is probably the reason for lower specific gravities for conifer wood grown under intensive culture. Intensive culture jack pine and larch fibers were only one-third as long as fibers from older mature wood, but improved pulping processes have made fiber length less important. However, more reaction wood is produced under intensive culture than under conventional silvicultural practices probably due to the accelerated growth rates.

In one study pulp yields of tension wood and normal wood were 60 and 53 percent, respectively. Al-

Trees from the first SRIC plots are used for a multiple of research purposes. After they are weighed to determine total above-ground biomass yield, the wood is used in utilization tests.

though paper from tension wood had inferior strength properties to that from normal wood, the properties of kraft paper produced from SRIC *Populus* are still within acceptable ranges. Tension wood fibers resisted collapse during beating and produced a thicker, more porous sheet, but the pulp was still clearly acceptable after refining.

Wood produced from 8-year-old jack pine and larch grown under SRIC was also found to be acceptable for kraft pulping, with 41 percent pulp yield for jack pine and 39 percent for larch. On the basis of handsheet strength tests including burst, tear, and tensile, larch was slightly superior to jack pine. The acceptability of *Populus* and the conifer raw material produced under a SRIC system differed little. Thus, it was concluded that biomass yield and clonal differences are the major factors for determining the most promising species and clones for SRIC.

Wood produced under intensive culture has been found to be acceptable for kraft pulping. The wood may also be suitable for thermomechanical pulping.

Wood grown under SRIC was also tested in thermomechanical pulping processes, which offers the advantages of higher yields and lower capital investments than kraft pulping. Tests showed this wood to be inferior to pulps obtained from mature wood because fiber lengths were shorter; fiber length is more critical for obtaining paper strength for thermomechanical pulps than for kraft pulps. However, optical properties were generally good, which suggests that blending of mechanical and kraft pulp may be possible. Bark content was a major factor in the lower performance of SRIC produced wood, which could be decreased by longer rotations and improved methods of whole tree chip segregation.

This whole-tree chipper automatically separates some of the foliage from the chips. The chips may be further separated by the Vacuum Airlift Segregation process.

Intensive cultured *Populus* may also be suitable as a raw material for producing flakeboard, a structural particleboard. Tests on five *Populus* clones showed clonal variation in board strength properties, with the better clones producing boards exceeding industrial guidelines for strength properties. Bark reduced board strengths much less than was expected.

Another alternative use for Populus foliage is animal feed supplement. Recently matured Populus leaves have been found to contain levels of nitrogen, carbohydrates, and pigments comparable to forage crops. Feeding tests with ruminants showed the foliage to be acceptable, although the palatability of clones differ.

To alleviate the problems resulting from high bark content in the manufacture of both reconstituted wood products and pulp and paper, a vacuum airlift segregation (VAS) process was developed to separate whole tree chips into components— wood chips, bark, foliage, and fines. In the VAS process, chips are spread over a continuously moving wire mesh conveyor belt that passes under a series of vacuum hoods, which separates the components on the basis of differences in terminal settling velocities of the particles.

Populus *foliage has been found to be acceptable ruminant feed, although the palatability appears to vary by clone.*

Processing systems such as the VAS offer numerous alternatives for the utilization of the biomass, depending on the market demands and industry objectives. Four single- and multiple-use alternative systems are summarized below for 5-year-old *Populus* grown under SRIC at 1.2 m spacing.

System	**Pulp yield** *Metric ton/ hectare*	**Energy** *M kcal/ hectare*	**Feed** *Metric ton/ hectare*
Pulp only	42	—	—
Energy only	—	200	—
Pulp and energy	27	68	—
Pulp, energy, and animal feed	27	48	5

DISEASES OF INTENSIVELY CULTURED SPECIES

Leaf rust causes defoliation of Populus *before the end of the growing season. As shown, severity of damage varies between clones so selection will be made for those clones that are least susceptible to leaf rust.*

Research Problem

Intensive culture systems may be more vulnerable to disease than conventional mixed species stands because they contain only a few species or hybrids and they may facilitate transmittal of pests because they are closely spaced. At any rate, the susceptibility of a species to pests and the possible control methods must be determined before any species or clone is widely planted.

Research Objectives

It is well known that *Melampsora medusae* leaf rust, *Marssonina brunnea* leaf blight, and *Septoria* *musiva* Peck leaf spot and canker are the most prevalent poplar diseases in the United States. The susceptibility of various *Populus* clones to these and other diseases will be determined through this research. Additionally, the incidence and severity of these diseases within the north-central region of the United States will be examined. Integrated control methods to reduce damage from these diseases will be recommended.

Research Results

The screening of clones for disease susceptibility throughout the intended establishment range is extremely important. *Populus* clones were planted at each of 13 sites throughout the Midwest in 1976 and 1977, with an intent to monitor the plots for 10 years. After one growing season, it was found that the most serious diseases were *Marssonina* leaf spot, *Melampsora* leaf rust, *Septoria* leaf spot, *Cytospora* canker, and *Septoria* canker. The severity of each of the diseases varied widely in the region.

Leaf rust injures trees by causing leaf damage and defoliation, and when severe, increases susceptibility to other diseases. Incidence was found to vary greatly between clones, and fungicide treatment delayed defoliation but did not prevent severe rust damage for one hybrid, *P. deltoides* x *P. balsamifera* 'Northwest'. Infection is usually most severe on lower leaves, thus it generally affects basal diameter growth but not height growth.

INSECT PROBLEMS IN INTENSIVE CULTURE

Research Problem

Because intensive culture crops are expected to be fairly uniform in species, age, spacing, and genetic composition, the potential for insect outbreaks may be greater than in forests with a wide range of species and ages. However, the SRIC system affords the opportunity of using cultural tools to control insects before they become destructive.

Natural enemies of *Populus* include more than 150 insects. The most destructive of these are leaf aphids, which feed on leaves and ultimately defoliate the trees. Jack pine and larch also have numerous defoliating, sapsucking, and shoot-stem boring insect pests.

Research Objectives

Insect damage depends on the number of insects attacking the tree or stand, the part of the tree infested, the season of attack, and the age of the tree. After the potential insect pests are identified, clones resistant to these pests may be selected, although resistance includes extremely complex factors such as nutritional status and vigor of the tree.

Control methods for insects in intensive culture systems will be identified. These may include site preparation to eliminate insect habitats occupied in other stages of the life cycle, fertilization to improve nutritional status of the tree or alter tissue components essential for specific insect pests, irrigation to eliminate the water stress conditions that are often causes of insect outbreaks, and hybridization to alter plant density. Close planting may provide stress from competition or modify environmental conditions to limit some insects and favor others.

Research Results

Insect damage has been surveyed on established intensive culture plots of *Populus* throughout the North Central States. Aphids, *Chaitophorus populitoliae* (Oest.), were found to cause the greatest defoliation damage, although considerable differences in severity of attack were observed among clones.

Further tests on the impact of defoliation in relation to clone and spacing have begun. An experiment to test the effects of various degrees and timing of defoliation on yield is in progress— certain percentages of leaves are manually removed at various times during the growing season. The effects of girdling and boring damage will be determined in similar experiments by physically damaging the trees. When the season and severity of impact can be related to actual yields, cultural control methods will be prescribed.

DESIGN OF MECHANIZED EQUIPMENT FOR INTENSIVE CULTURE SYSTEMS

This tree planter was modified for planting unrooted cuttings. The operators place the 8-inch cuttings vertically in a trench and the planter wheels pack the soil around them.

Research Problem

Labor costs are rising in all sectors of the economy, and forest and agricultural operations have become increasingly mechanized in order to lower production costs. Intensive culture systems must also be mechanized. Although they require many cultural operations widely practiced in agriculture, commercial agricultural equipment is generally not suitable for tree crops.

Researchers have improvised equipment for planting cuttings, cultivating, and irrigating. Small research plots have been harvested with chain saws. Yet these methods will be impractical for even the large-scale pilot plantings already established. Harvesters used for current silvicultural operations are not suitable for closely-spaced stands, which have small stems and multiple stems on each stump after the first rotation. An entire systems approach must be developed for harvest, collection, and delivery of wood to the pulp mill or energy conversion facility.

Research Objectives

Modifications of commercial agricultural and horticultural equipment will be investigated first, although substantially different equipment for intensive culture systems may eventually be developed if these modifications do not perform satisfactorily. In particular, equipment needs for planting, cultivation, fertilization, and irrigation will be assessed.

Probably the most critical need is for appropriate harvest equipment. Design criteria for a small-diameter short-rotation harvester are currently being developed, and preliminary designs for the cutting head are already underway.

Research Results

Engineers working with this program have modified existing tree planting equipment to accommodate the large unrooted and rooted cuttings used in the large-scale field plantings. These modifications are currently being tested in the field and will be further improved as operational data are obtained. Similarly, a traveling irrigation system to deliver water over 3 to 9 m-high trees has been installed for the large field plantings. The irrigation system performance will be critical as the trees increase in height toward 9 m or taller, because the system must be able to deliver water uniformly over the land area.

Preliminary design criteria have been developed for the mechanized harvest equipment. In general, it must be capable of harvesting one or more rows of the plantation at one time, severing each tree sequentially in the row, and forwarding the material to the landing site. The lack of information about optimal spacings and rotation age (and thus stem diameter and height) make the design efforts and equipment development a continuous process. Consequently, it is highly unlikely that the first generation of small-diameter harvesters developed will be those which are ultimately commercially produced.

To ensure an acceptable level of regeneration by coppicing, the harvester must make a clean cut surface and provide minimal pressure against the stumps and root systems. It must be able to cut at low stump heights and handle the multi-stem tree that will develop in coppice rotations of hardwoods. The wood will probably be used as chips, so the harvester must simultaneously chip the wood or a whole-tree chipper must be present at the landsite. Existing chip trucks will be suitable for final transport of chips to the mill or conversion site.

COST OF PRODUCING WOOD FOR FUEL AND FIBER

The effectiveness of herbicides in reducing weed competition (left) compared to the control (right). When large field tests are conducted for such intensive culture practices as weed control, the costs and effectiveness of alternative treatments can be compared.

Research Problem

SRIC systems have been explored in response to rising land prices and taxes, increasing demands for recreation and nonforest uses of forest land, escalating future fiber demands, and rising costs of conventional energy. The system appears to offer resource managers the opportunity to supply the same quantity of fiber on much less acreage and the opportunity to grow energy feedstocks at competitive prices. An additional significant attraction of this system is the potential realization of an equivalent return on investment with 6 to 10 years after planting, rather than the 30 to 60 years necessary for conventional silvicultural systems.

Before intensive culture management will be widely accepted by land managers, however, detailed information on the production costs and anticipated revenues must be obtained. Estimates of the economic feasibility of intensive culture systems for fiber and fuel are needed to compare with conventional silvicultural systems for fiber and alternative energy supplies, such as coal. Although only preliminary economic analyses can be made with the information now available about yields under specific treatments, the sensitivities of the final production costs to various cultural treatments are needed by research scientists.

Until basic SRIC growth information under specific treatment regimes is readily available, economic evaluations will be partially made by using a break-even analysis technique. Break even analysis permits the physical yields (e.g., dry tons per acre) or financial yields required to cover all costs included in a specific production schedule to be estimated. In addition, the sensitivity of total production costs to individual costs such as land rent, stand establishment, fertilization, irrigation, and harvesting will be determined.

As better biological growth information and production management inputs are obtained from larger-scale plantings, more sophisticated economic analyses for calculating present net worth and internal rates of return will be incorporated into the evaluations. For example, cashflow analyses will be used to calculate costs and benefits of growing *Populus* 'Tristis #1' for two 10-year rotations and three spacings, with emphasis on impacts of different interest rates, inflation and price trends, and Lake States land use alternatives.

The cashflows will be contrasted with energy flows to determine cost-energy tradeoffs. In addition, the minimum operational size will be identified. The costs and energy balances will be assessed for biomass on the stump, delivery of whole-tree chips at 100 percent moisture content, and delivery of kiln-dried whole-tree chips.

Research Results

Break-even analyses were prepared for each of eight management alternatives ranging from 2-year rotations with numerous coppice harvests to 15-year rotations without coppicing. Low, medium, and high cost estimates were used for each production activity within each of the eight management programs. All management costs were compounded to the time of harvest or the end of the rotation. These are the minimum values that must be recovered when selling the wood before any profit is returned.

Using recent simulation biological growth results and assuming that energy from wood is worth $1.00 per million Btu's and dry fiber is worth $30.00 per ton, the eight management alternatives were evaluated for potential profitability. Alternatives with rotation ages of 10 to 15 years, one coppice rotation, and average yields of 8.4 to 10.0 dry tons/acre (18.8 to 22.4 mt/ha)/year total biomass, appeared potentially profitable for both energy and fiber. The cost of wood produced under 4- to 5-year rotations approached $1.00/mmBtu and $30.00 dry ton only where low management costs were assumed. In general, the analysis suggests that the longer rotations will be more profitable than extremely short ones.

Because production costs are different between the first harvesting period and the following coppicings, the time required to recover the investment, i.e., when compounded yields exceed compounded expenditures, is also an important consideration. The farther into the future the payback occurs from initial point, the greater the risk of the investment and the more important the success of scheduled coppicings.

Evaluating the sensitivity of total production costs to changes in various cost factors provides considerable information for setting research priorities. Emphasis should be placed on cultural practices that will most decrease the total production costs if their costs were decreased. For example, a $10/acre decrease in fertilizer cost would decrease the cost of energy by $0.20/mmBtu; a $10/acre decrease in harvest costs would decrease the cost of energy by $0.15/mmBtu; and a $10/acre decrease in first-year establishment costs would decrease energy costs by $0.08/mmBtu. This result suggests that costs could be significantly reduced if fertilizer requirements were decreased by planting nitrogen-fixing cover crops, alder, or other nitrogen-fixing tree species.

More detailed economic evaluations using cash-flow analyses are in progress. Operational information on machine production rates, man-hours, and fuel consumption rates have been collected from the large-scale plantings at the Harshaw farm near Rhinelander, Wisconsin. Data will also be available from the pilot-sized intensive culture system now established in the Lake States. Costs and energy requirements have been compiled for the purchase and maintenance of equipment, and the cost curves and energy inputs for alternative equipment combinations are being developed.

INDUSTRIAL COOPERATORS

Populus *grows well on sandy sites irrigated with secondary pulp mill effluent.*

Research Problem

Industry will ultimately determine the commercial success of intensive culture concepts. Some of the intensive culture techniques developed under research conditions may not be feasible in large industrial woodlands programs. Therefore, it is extremely important to cooperate with industrial foresters throughout the research and development effort.

Research Objectives

The technical and economic feasibility of intensive culture cannot be determined by small field experiments such as those conducted at Rhinelander. Large plantations must be established to learn whether research results can be applied in industrial forest operations and to obtain information about the cost of operational intensive culture systems.

More than 30 million gallons of effluent are produced daily by a large modern paper mill in the Lake States. Currently, holding ponds are used for biological treatment of wastes before discharge into a river.

Research Results

One of the pulp mills in the Lake States has been exploring the possibility of using mill effluent from a secondary treatment plant as an irrigating medium on trees growing on land adjacent to the mill. The company is interested in obtaining uniform high quality wood and in reducing transportation costs, harvesting costs, and taxes on vast acreages of forest land.

Moreover, the company is concerned about developing a means of disposing of some 30 million gallons of effluent a day, which is presently treated and then discharged into a river. One possible use for this effluent is irrigation of intensive culture trees. In areas of the United States where water is limited and industrial plants have to find a way to dispose of effluent, irrigation with treated effluent may be a solution to both problems.

A large-scale pilot study is in progress to test the most intensive methods for growing fiber. A 40-acre site has been cleared, and tilled, and *Populus* cuttings will be planted at two spacings. An irrigation system to distribute the effluent will be installed to maintain an optimum moisture regime for the trees. In addition, a 1-acre test plot of willow (*Salix*) and several *Populus* clones has been established to determine the tolerance of these species to high applications of effluent and the effect of the effluent on groundwater quality.

The groundwater at the site has been thoroughly mapped to identify depth, direction of flow, and chemical nature. Throughout the study it will be monitored to detect changes due to irrigation with the effluent.

Water sampling probes are used to monitor the groundwater quality under and near the site where effluent is being applied.

Wastewater effluent from the pulp mill holding ponds (top) is pumped (middle) to the experimental fields. There, it is applied onto the intensive culture Populus *with a flood irrigation system (bottom). Flood irrigation is used to avoid the possible odor problems of overhead spraying.*

As a separate effort, more than 1,200 acres of *Populus* and *Alnus* were planted in 1978 by the Packaging Corporation of America near Manistee, Michigan, in cooperation with the Maximum Yield Program. Nurseries of superior clonal material were established and hardwood cuttings were planted in 3.3 x 3.3 m spacings. Agricultural techniques and equipment were used to mechanically prepare the site, fertilize, and cultivate. Smaller acreages were established during the previous 3 years, with considerable failure due to stand establishment problems and weed competition. Successful cultural practices for many of these problems have gradually been worked out and survival of trees for 1978 was more than 80 percent. It is expected that an additional 1,200 acres will be established in 1979.

Commercial agricultural equipment is used for site preparation. In some fields, the mills' sewage sludge was applied to provide soil amendments.

Large plantings have been established by Packaging Corporation of America to obtain operational and economic information about meeting their mill needs with intensively cultured Populus.

At the Packaging Corporation of America plantations, a 20-foot cultivator is used to clean three rows of Populus *at one time. About 100 acres can be cultivated daily during the first growing season.*

Some of the older plantings are growing well, particularly this stand of 2-year-old Populus. *Wide spacings were used because the trees will be grown for 10-to 15-year rotations.*

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Since 1971 there has been significant progress in greatly increasing yields of wood and energy (biomass) from intensively cultured plantations compared with natural stands. This publication reports the results of studies and summarizes the "maximum-yield" research in progress at the North Central Forest Experiment Station.

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DRYING HARDWOODS WITH IMPINGING JETS

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DRYING HARDWOODS WITH IMPINGING JETS

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Attempts to develop a more efficient way to dry lumber than conventional kiln-drying have led to recent developments in wood drying technology throughout the world. Spurred on by the rising cost of energy and reduced availability of some of the more popular species, the wood industry has tried to conserve energy and reduce degrade during the drying of wood.

Recently, several nonconventional lumber dryers and drying processes have been operated commercially. For example, a continuous kiln that dries radiata pine studs at temperatures to 300°F was developed by the Australian Commonwealth Scientific and Industrial Research Organization (Anonymous 1975). The dehumidification-refrigeration drying method, developed in Europe and modified with auxiliary heating and steam spray, has been gaining acceptance for drying refractory hardwoods in the United States (Wolfe 1977). Finally, the continually rising temperature or CRT process, involving the maintenance of a nearly constant rate of drying by continuously increasing the temperature in a kiln until completion of drying, has been adopted by many kiln operators throughout North America (Dedrick 1973).

The large capital investment by industry in several countries throughout the world to implement new drying techniques has encouraged researchers at Carbondale, Illinois, to examine other ways to dry wood more effectively. We felt that jet impingement of air on the surface of the wood to increase dryer efficiencies and reduce drying time was worth investigating. This drying method has several advantages over more exotic processes for drying. Since veneers have been dried commercially by jet-drying for over a decade, much of the technology for this type of drying is already available. Also, a jet dryer can be built to accommodate several alternative energy sources (fuel oil, gas, or steam) unlike, for instance, dielectric heating, which requires electricity exclusively.

HIGH TEMPERATURES AND IMPINGING JETS

High temperature drying refers to drying wood above 212°F in the presence of moist air generally at atmospheric pressure, although vacuum or high pressures can be used. The limits of temperature in commercial high temperature lumber kilns have been around 250°F for hardwoods and 280°F for softwoods. High temperature drying of softwoods has met with more success than hardwoods, because many softwoods (which are more permeable and uniformly structured than hardwoods) are easier to dry and the surface quality of softwood lumber is not always as important as that for hardwood lumber. High temperature drying cuts drying time considerably when compared to conventional kiln-drying, but greater susceptibility of the wood to surface darkening, warpage, checking, collapse, and casehardening has discouraged the wood industry from using this method (Wengert 1972).

Air circulation in commercial lumber dryers is generally directed parallel to the drying surface of the wood. When drying with parallel flow of air, a thin boundary layer builds up on the surface of the wood, thus reducing mass and heat transfer from air to wood. By directing small jets of air perpendicular to the wood surface, the boundary layer is broken up by the turbulence caused by the impinging jet (fig. 1). This jet impingement action produces a three- to five-fold greater heat transfer than parallel circulation dryers, resulting in shorter drying times and more efficient use of input energy (Arganbright and Resch 1971).

The jet-drying of lumber poses special problems in dryer design not encountered in veneer drying. Lumber is much thicker, takes considerably longer to dry, develops greater internal stresses, and is stiffer than veneer, which can be bent around rollers and dried in minutes as it moves through a dryer. Possibly be-

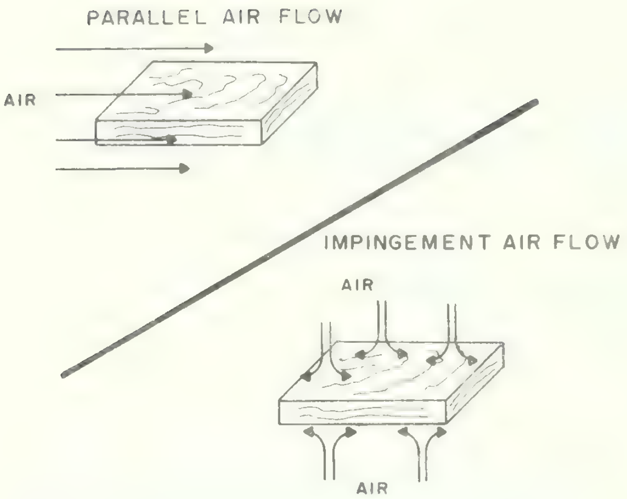

Figure 1.— *Direction of flow relative to the board surface for impingement and parallel air flow.*

cause of these difficulties, the jet-drying of lumber greater than ½-inch stock has not been reported in the literature. Two previous studies examined the jet-drying of thick southern pine veneers in commercial dryers. Koch (1964) was able to dry $^7/_{16}$-inch-thick veneer at 300°F and 3,500 fpm air velocity in one hour. Similarly, Kimball (1968) dried ⅜-inch veneer at 300°F and 4,000 fpm air velocity in 53 minutes.

PROTOTYPE DRYER

A brief description follows of the prototype jet impingement dryer, capable of handling lumber to a maximum size of 4 inches thick by 12 inches wide by 30 inches long at temperatures from 80 to 400°F and air velocities through the jet from 1,000 to 9,000 fpm. Details are discussed by Rosen (1977).

The dryer is a closed loop recirculating system comprising an industrial centrifugal blower capable of providing 1,800 cfm of air at 15 inches static pressure, a 10 kw open coil duct heater, and a jet section where plenums direct the hot, moist air through two boxes containing opposing bans of $^3/_{16}$-inch jet holes (fig. 2). The ducts are made of 20-gauge galvanized steel, 14 inches in diameter. Temperature is automatically controlled to ± 2°F, and humidity is automatically controlled to a wet bulb of ± 2°F by either venting air if the wet bulb is high or adding steam if the wet bulb is low. Air flow rates are measured from an inline orifice plate and adjustments to air flow are made with a damper on the outlet of the blower.

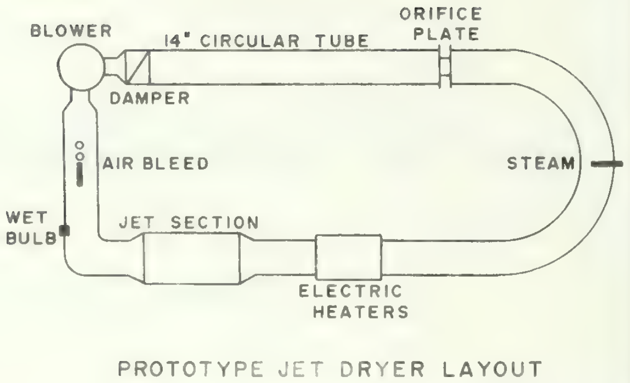

Figure 2.— *Layout of major components of jet dryer system.*

Wood ready for drying is placed in a restraining rack, which tightly holds the wood on the sides and ends to reduce warp. The wood is loaded through the top of the jet section onto a carriage which reciprocates the boards between the opposing banks of jet holes in 6-inch strokes at 1.33 fpm, so that air is directed equally on opposite lumber surfaces. Movement of the wood relative to the jet holes is necessary for directing the hot air jets to different portions of the wood.

INFLUENCE OF OPERATING VARIABLES ON DRYING TIMES AND WOOD QUALITY

The first step towards development of drying schedules for the jet dryer was to establish relations between drying times and several of the operating variables of the jet dryer. Drying temperature, air velocity (through the jets), and relative humidity (or wet bulb temperature) were thought to have the greatest influence on drying rates. Two popular and permeable species, silver maple (*Acer saccharinum*) and yellow-poplar (*Liriodendron tulipifera*) were dried green from the saw over a range of conditions to establish these relations.

Each run consisted of two boards, 30 inches long, 6 inches wide, and $1^1/_{16}$ inches thick ($^4/_4$-inch thickness). Silver maple boards $2^1/_8$ inches thick ($^8/_4$-inch thickness) were also run. The boards were not end-coated. Silver maple boards were dried over a range of temperatures from 225 to 400°F and air velocities from 1,000 to 9,000 fpm at a fixed wet bulb temperature of 180°F. Yellow-poplar boards were run over a range of dry bulb temperatures from 225 to 350°F and wet bulb temperatures from 130 to 210°F at a fixed air velocity of 3,000 fpm. Weights were taken at intervals over the drying period to establish drying curves. Drying was terminated when the boards reached about 6 percent moisture content, as estimated by assuming the boards were the same moisture content as thin sections removed from the ends of the board. Boards were conditioned for 1½ hours for $^4/_4$-inch thickness and 3 hours for $^8/_4$-inch thickness at 200°F dry bulb and 190°F wet bulb temperature to relieve stresses and reduce moisture gradients in the wood. Six boards were dried for each condition for $^4/_4$-inch lumber and four boards for the $^8/_4$-inch lumber.

The time required for the wood to be jet-dried to 8 percent moisture content (hereafter referred to as the drying time) was chosen as a basis for comparison of different drying conditions. The drying time was determined for each board from plots of moisture content versus time in the dryer and an average calculated for the four to six boards dried at each condition. Comparisons were somewhat complicated by variations in initial moisture content of 83 to 97 percent in silver maple and 89 to 119 percent in yellow-poplar, as well as variations in the amount of heartwood and sapwood in the boards, especially in yellow-poplar.

The following were found to be true of the influence of temperature and air velocity on drying time. The trends were the same for wood thickness and operating conditions not shown in the figures.

1. Drying time decreased as temperature increased, but the relative decreases above 300°F were small (fig. 3).
2. Drying times were not significantly decreased by increasing air velocity above 3,000 fpm (fig. 4).

Drying times for yellow-poplar were not affected by change in wet bulb temperature for dry bulb temperatures from 250 to 350°F. Similar results were found by Schneider (1972) when pine and beechwood were dried at high temperatures. Although variation in wet bulb temperatures did not influence drying rates, high wet bulb temperatures were best in the dryer to maintain the quality of the dried lumber. When wood is being dried by high temperature jet, the possibility of degrade as a result of overdrying is much greater than when drying at conditions in a conventional kiln. Hardwoods are generally dried no lower than 5 percent moisture content in the United States, before conditioning to a slightly higher moisture content. Thus, to insure no board would go below 5 percent moisture content, the highest temperature

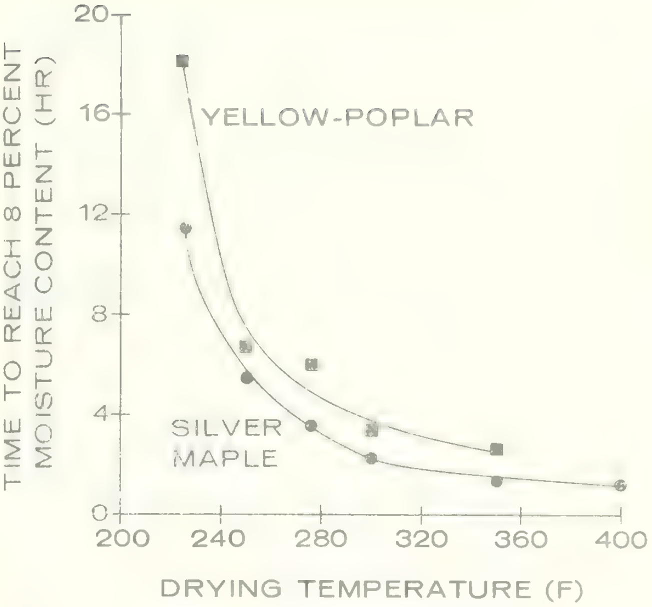

Figure 3.—*Influence of temperature on drying time of $^4/_4$-inch silver maple and yellow-poplar at 3,000 fpm air velocity and 180°F wet bulb. Each point is the average of six boards.*

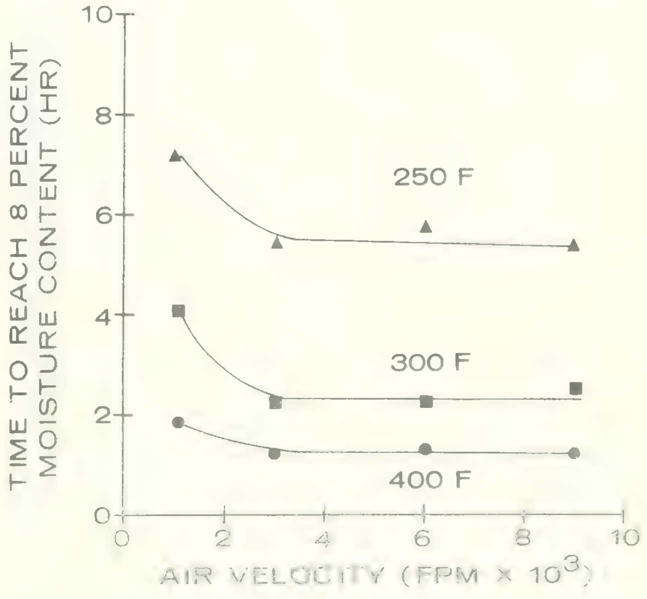

Figure 4.—*Influence of air velocity on drying time of $^4/_4$-inch silver maple at various dry bulb temperatures (180°F wet bulb). Each point is the average of six boards.*

allowable at the end of drying would be 240°F, assuming the dryer could maintain an atmosphere entirely of water vapor (fig. 5).

The problem of localized uneven drying within a board is seen with yellow-poplar. Since yellow-poplar sapwood dries considerably faster than the heartwood (fig. 6), overdrying of the sapwood and underdrying of the heartwood can result in degrade of the wood. Careful control of relative humidity can reduce this degrade, as explained later.

Because of the limited number of boards dried in the jet dryer for each condition, quantitative comparisons of defects such as honeycomb, checking, etc. were impractical so only qualitative results are discussed. Surface darkening, honeycomb, and end checking were the most prevalent defects in the jet-dried boards.

The surface of jet-dried wood was darker than the interior and ranged from light tan, when dried at 225°F, to toast brown, when dried at 400°F. The dark surface layer on wood dried below 350°F was less than 0.01 inch thick and planed off when the board was surfaced. Knots and wane dried faster than clear wood and charred at temperatures above 300°F. Severe honeycomb and end checking as observed in $^8/_4$-inch silver maple boards at all operating conditions; thus, green $^8/_4$ silver maple could not be practically jet-dried at high temperatures. Honeycomb was also present in $^4/_4$-inch silver maple, but the defect was mainly confined to the mineral-streaked areas of the wood and severity decreased considerably at drying temperatures of 300°F and below. Surface checking on the borders of the mineral-streaked areas, not observable immediately after drying, occasionally developed after the wood was stored for several weeks. End checking and honeycomb were found in most yellow-poplar boards, but these defects were confined to the heartwood and were not as severe as in the $^8/_4$-inch silver maple boards.

Based on the influence of dry and wet bulb temperature and air velocity on drying time and wood quality, schedules were developed for silver maple, yellow-poplar, and black walnut. Boards of silver maple and yellow-poplar, cut to the same dimensions as the jet-dried boards, were dried in 1,500 board-foot capacity, steam-heated conventional kilns for direct comparison with the jet-dried wood. Boards were stacked 3 feet high with ¾-inch stickers before applying standard schedules as recommended by Rasmussen (1961). All jet- and kiln-dried boards were measured for crook, cup, bow, twist, and volumetric shrinkage and examined for honeycomb,

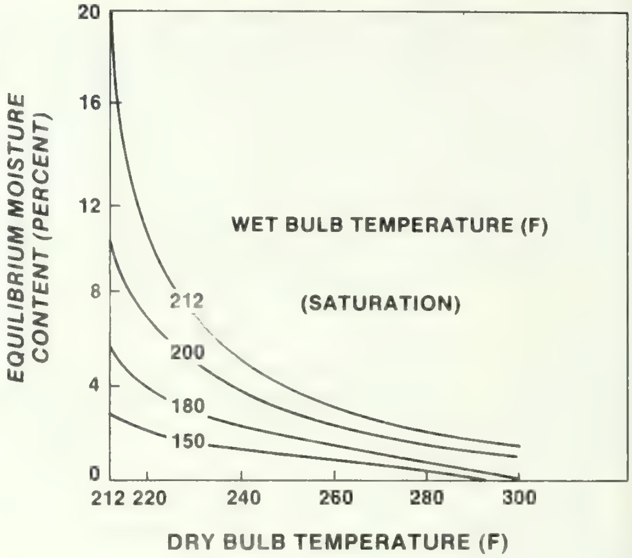

Figure 5.— *High temperature equilibrium moisture content of air-water vapor mixtures at atmospheric pressure (Kauman 1956). The saturation curve at 212°F wet bulb is the maximum equilibrium moisture content obtainable at a given dry bulb temperature.*

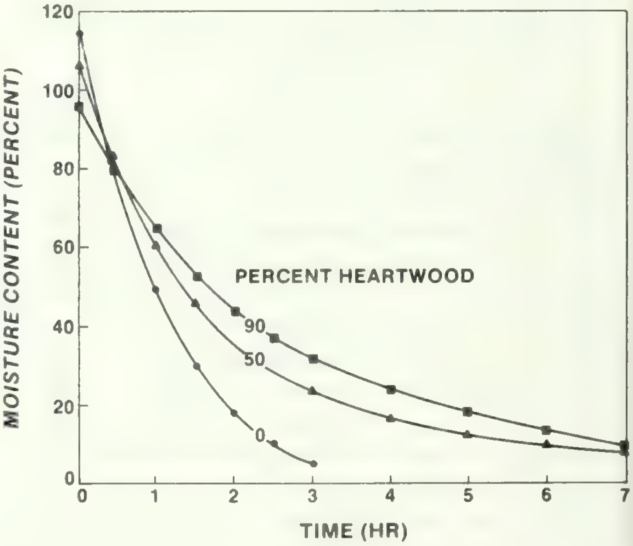

Figure 6.— *Typical drying curves of $^4/_4$-inch yellow-poplar at 300°F (200°F wet bulb and 3,000 fpm air velocity), showing the influence of heartwood content of the wood on drying rate.*

checking, and collapse. Shell and core moisture content, as well as casehardening, was determined for half of the jet-dried boards and three boards from each kiln load.

SILVER MAPLE SCHEDULE

The schedule chosen to jet dry $^4/_4$-inch silver maple was the severest practical schedule in the jet dryer: 300°F dry bulb temperature and 3,000 fpm air velocity. Wood dries 36 times faster under these conditions than it does in a conventional kiln (tables 1 and 2). With the exception of twist, which was better for jet-dried wood, warpage was comparable (not statistically different at the 95 percent level) for both jet-and kiln-dried wood. Volumetric shrinkage was reduced; thus, high temperature drying provided some dimensional stability to the wood. Casehardening was slight in both jet- and kiln-dried wood. Shell-to-core moisture content, not evaluated in kiln-dried wood because of eqipment malfunction, showed only a 2 percent difference in jet-dried wood.

YELLOW-POPLAR SCHEDULE

Since the heartwood of yellow-poplar dries slower and is more subject to drying defects than the sapwood, severity of the drying conditions is controlled by the heartwood. We tried a two-step high temperature schedule to produce acceptable and rapidly dried yellow-poplar. The first step was at a temperature of 350°F for one hour to drive off most of the free moisture from the wood (table 3). Rapid removal of the water kept interior board temperatures well below 350°F. Conditions were then changed to 220°F dry bulb and 195°F wet bulb for 18 hours of drying. Because equilibrium moisture content (EMC) of the wood was 5.5 percent at the latter conditions, the wood could not go below this moisture content. As drying pogressed, the sapwood dried to around 5.5 percent moistue content and remained at this moisture content as the slower drying heartwood approached 6 percent moisture content. As sapwood percentage decreased, the amount of moisture loss after the 350°F drying step decreased. At the end of the drying period, the sapwood board was at the EMC, whereas the boards with heartwood were slightly higher. The difference in moistue content among the three boards was further reduced after conditioning.

Table 1.—*Conventional kiln and jet dryer schedules for drying $^4/_4$-inch silver maple and yellow-poplar*

CONVENTIONAL KILN[1]

Species	Dryer time	Dry bulb temperature	Wet bulb temperature	Moisture content
	Hours	°F		*Percent*
Silver maple				79
	0-45	130	123	50
	45-52	130	120	43
	52-72	130	115	30
	72-84	140	100	23
	84-94	150	100	17
	94-104	160	110	12
	104-126	180	130	5
	126-141	160	145	7
Yellow-poplar				102
	0-94	150	143	38
	94-114	150	140	26
	114-119	160	120	22
	119-125	160	110	18
	125-137	170	120	12
	137-161	180	130	6
	161-185	160	145	8
JET DRYER[2]				
Silver maple				83
	0-2.4	300	180	6
	2.4-3.9	200	190	8
Yellow-poplar				92
	0-1	350	180	35
	1-19	220	195	8
	19-24	200	190	9

[1] Rasmussen (1961).

[2] Air velocity, 3,000 fpm.

The two-step high temperature schedule with the jet dryer was eight times faster than conventional kilns for drying wood (table 1). As with silver maple, warpage was comparable, shrinkage was less, and shell and core moisture differences were small (table 2). End checking was present in both kiln- and jet-dried lumber but could have been reduced by end-coating the boards. The initial high temperatures in the jet dryer caused darkening of and slight honeycomb around knots.

Table 2.—*Comparison of properties of kiln- and jet-dried $^4/_4$-inch silver maple and yellow-poplar*[1]

Property	Silver maple		Yellow-poplar	
	Conventional kiln	Jet dryer	Conventional kiln	Jet dryer
Moisture content		*Percent*		
Green	79	85	102	92
Dry	7	8	8	9
Shell	—	7	7	7
Core	—	9	7	8
Dry warpage		*Inches*		
Twist	0.22	0.06	0.09	0.14
Bow	0.10	0.17	0.05	0.06
Crook	0.08	0.14	0.03	0.06
Cup	0.10	0.07	0.07	0.07
Volumetric shrinkage		*Percent*		
	10.9	7.6	12.1	9.6
Boards		*Number*		
	70	6	85	20

[1] As per schedules described in table 1.

Table 3.—*Influence of heartwood/sapwood of $^4/_4$-inch yellow-poplar on drying rate of boards jet-dried in two high temperature steps*

Time (hours)	Dry bulb temperature	Wet bulb temperature	EMC	Sapwood (percent) 100	80	50
				Moisture content		
	------°F------		--------*Percent*--------			
0	—	—	—	91.7	84.4	86.8
0-1	350	180	0	29.8	30.1	38.4
1-19	220	195	5.5	5.6	8.2	9.8
19-24	200	190	10.8	7.3	9.5	9.8

BLACK WALNUT SCHEDULE

Limited work was done on jet-drying the refractory wood, black walnut (Juglans nigra). Attempts at high temperature jet-drying $^4/_4$-inch black walnut were unsuccessful because of severe honeycomb and collapse in the dried boards. We tried a combined low and high temperature schedule plotted in figure 7. The surface of the wood was kept moist by maintaining the wet bulb temperature just a few degrees below the dry bulb temperature until the wood moisture content dropped below 30 percent. Moisture gradients and internal stresses were thus kept at a level that did not degrade the wood.

Twelve boards of $^4/_4$-inch black walnut heartwood, 30 inches long by 6 inches wide and end-coated with asphalt mastic, were jet-dried according to the schedule in figure 7. Boards were dried from approximately 60 to 6 percent moisture content in 60 hours and then conditioned for 12 hours to 7 percent moisture content. Volmetric shrinkage was 11 percent and shell-to-core moisture contents differed by only one percent. The quality of the wood was good; checking and honeycomb was slight and limited to 2 inches from the ends of the boards. Casehardening was slight and might have been eliminated by a longer period of conditioning.

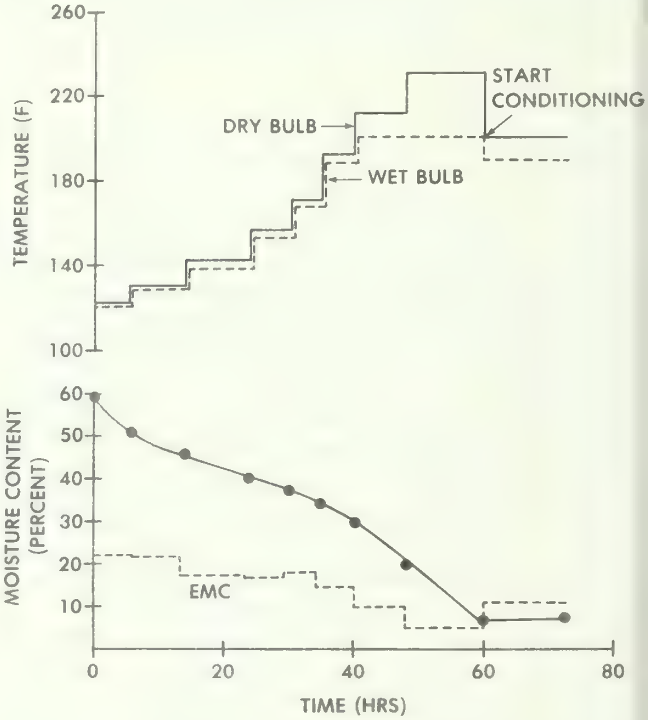

Figure 7.— *Drying schedule and moisture contents for jet-dried $^4/_4$-inch black walnut. The top graph shows dry bulb (solid line) and wet bulb (dotted line) temperatures versus time. The bottom graph shows the moisture content (solid line— each point is an average of two boards) and the EMC (dotted line) associated with the dry and wet bulb temperatures of the top graph.*

SUMMARY

Four-quarter-inch silver maple and yellow-poplar were jet-dried at high temperature in a fraction of the time required in a conventional kiln. The jet dryer also dried 4/4-inch black walnut in 72 hours. The quality of the jet-dried wood was good. A complete evaluation of wood quality should be done on full size lumber, but these promising results should encourage further work on jet-drying of lumber.

An important point brought out by this study is the necessity of maintaining high relative humidities during high temperature drying. Although high temperatures result in faster drying, the wood can become seriously overdried, producing excessive degrade if high humidities are not maintained at the end of the drying schedules. To illustrate this point, assume the conditions in a kiln are 225°F dry bulb and 150°F wet bulb. The EMC, or lowest moisture content to which the wood can be dried, is less than 2 percent (fig. 5) and overdrying of the wood can occur. By increasing the wet bulb to 200°F, the EMC is increased to 6 percent and overdrying of the wood is prevented. Unfortunately, batch kilns and continuous dryers, such as veneer dryers, are rarely capable of maintaining wet bulb temperatures above 180°F (Corder 1976). Kilns capable of achieving wet bulb temperatures of 200°F or better are desirable when woods that require a narrow distribution of moisture content (both among the boards or within individual boards, such as furniture grade lumber) are being dried. High temperature dryers for this lumber must be built tighter and with more insulation than in the past. Direct-fired kilns, in which relative humidity must be kept low to support combustion, are not practical.

Beware of the following problems when woods are being jet-dried at high temperature:

1. Knots that char and loosen.
2. Degrade and excessive surface darkening due to overdrying of the lumber.
3. Degrade in and around wet or dry pockets near stain or rot.
4. Surface darkening.
5. Honeycomb, checks, warp, etc., that are not immediately visible after drying but show up weeks afterward.
6. Excessive degrade in thicker material of a species from which thinner material was successfully high-temperature dried.
7. Highly corrosive environment caused by a combination of high temperatures, high humidities, and organic acids given off by the wood.

Although the challenges to construct and operate a commercial high temperature, continuous, jet-impingement lumber dryer are formidable, we believe the savings in drying time make this process worth considering.

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Silver maple, yellow-poplar, and black walnut lumber was dried in a prototype jet dryer over a range of temperatures from 120° to 400°F and air velocities from 1,000 to 9,000 fpm. Different drying schedules were developed for each type of wood. The quality of the jet-dried lumber was good and compared favorably with kiln-dried lumber.

KEY WORDS: *Liriodendron tulipifera, Acer saccharinum, Juglans nigra,* degrade, high temperature, humidity.

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Weight and volume equations and tables for **six upland hardwoods in southern Illinois**

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WEIGHT AND VOLUME EQUATIONS AND TABLES FOR SIX UPLAND HARDWOODS IN SOUTHERN ILLINOIS

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As the demand for lumber and wood products continues to increase, the need to achieve more complete and efficient utilization of our available timber resource becomes more urgent. In order to do so, we need to know the volume and weight of the entire tree and of its component parts. The tables presented in this report give the volumes and weights for six upland hardwood species— red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), white oak (*Q. alba* L.), hickory (Carya sp.), white ash (*Fraxinus americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.).

For each species, 40 trees were felled and measured. The trees were all harvested from within three 8-hectare areas on the Shawnee National Forest in southern Illinois. The aspect was predominantly southern, and the trees were located on slope positions ranging from ridgetop to valley bottom. The major soil types were Typic Hapludalfs, Ultic Hapludalfs, and Aeric Fluvaquants. The sample was stratified into three size classes (table 1).

After each tree was felled, the main stem was sectioned into approximately 2.5-m long segments up to a 10-cm top diameter inside bark (dib). The dib's were measured at the ends of the segments, and their volumes were calculated using Smalian's formula. Four 3- to 5-cm thick disks were removed from along the main stem, sealed in plastic bags, and returned to the laboratory for determining specific gravity, green weight:dry weight ratio, and bark:wood ratio.

Table 1.— *Sample characteristics*

Item	Red oak	Black oak	White oak	Hickory	White ash	Yellow-poplar
			No. of trees			
13-28 cm dbh	15	14	14	18	16	13
28-45 cm dbh	14	13	13	19	18	21
46 + cm dbh	11	13	13	3	6	6
			cm			
min. dbh	13.2	12.7	14.2	12.7	13.5	15.2
max. dbh	58.9	54.9	59.9	58.7	58.9	57.2
			m			
min. height	12.4	13.7	11.4	12.0	13.9	15.6
max. height	29.4	28.9	28.2	29.3	29.9	29.0

The rest of the stem and the branches were segregated into three classes— material greater than 10-cm dib, that between 5 cm and 10 cm, and that (including foliage) less than 5 cm. This material was weighed in the field on a platform scale. Three disks each were taken from the 5- to 10-cm and less than 5-cm material for laboratory analysis as above.

In the laboratory, a wedge-shaped sample was cut from each disk and weighed immediately to determine the green weight with bark. The bark was then removed, the green weight without bark was measured, and the green volume of the wood determined by means of a xylometer. Both wood and bark were then ovendried at 70C for 72 hours, the dry weight of the wood and bark and of the wood alone were measured, and the dry volume of the wood determined.

Data from one species, black oak, were used to select the form of the regression equations employed to develop the tables. Initial screening of possible equations narrowed the choice to the following five:

$$W = aD^b \tag{1}$$

$$\log W = a + b \log D \tag{2}$$

$$W = a + bD^2H \tag{3}$$

$$\log W = a + b \log D^2H \tag{4}$$

$$W = aD^bH^c \tag{5}$$

where W = either the green weight of the total tree or the green volume to a 10 cm top,

D = diameter breast height,
H = total tree height, and
a,b,c = regression coefficients.

The black oak data were divided into two 20-tree stratified random subsets, one subset was used to develop the equations and the second subset was used to test them. Based on the tests (equation 5) a robust nonlinear equation involving both dbh and total height, was selected. Regression equations were then developed to predict weight or volume for the following seven components for each species:

1. Total tree green weight above stump height (approximately 30 cm) including bark and leaves.
2. Green weight above stump height greater than 5 cm (2 in) in diameter including bark.
3. Green weight above stump height greater than 10 cm (4 in) in diameter including bark.
4. Ovendry weight above stump height greater than 5 cm (2 in) in diameter excluding bark.
5. Ovendry weight above stump height greater than 10 cm (4 in) in diameter excluding bark.
6. Green volume above stump height greater than 5 cm (2 in) excluding bark.
7. Green volume above stump height greater than 10 cm (4 in) excluding bark.

Both English and metric unit tables (3-16) are given for each of the above. The range of the data from which the equations were derived is outlined on the total green weight table for each species.

The final equations (table 17) derived from this study are reasonably accurate for the area in which the tree data were collected (table 2). The equations will predict weight or volume within an average of 9 percent for the individual study trees from which they were derived. The composite error for a stand of trees would generally be expected to be smaller than the average error for a tree.

The extent to which the equations can be generalized to other areas is not known, although the table values compare reasonably well with previously published values. As with other types of yield tables, preliminary testing is advisable before using them in other areas or sites.

Table 2.— *Summary of equation accuracy*
(In percent error)[1]

Item	Black oak	White oak	Red oak	Hickory	White ash	Yellow-poplar
GWBT	6.8	11.3	9.2	13.2	9.5	7.2
GWB2	7.4	11.5	7.6	13.1	11.0	7.7
GWB4	7.9	10.4	7.8	13.3	7.8	6.0
ODW2	7.3	11.2	7.2	12.9	8.3	6.9
ODW4	7.9	10.2	7.7	13.1	7.7	6.1
VOL2	7.0	11.8	7.4	12.9	8.1	6.8
VOL4	7.7	10.2	7.5	13.1	7.6	6.2
AVG	7.4	10.9	7.8	13.1	8.6	6.7

[1] Σ(measured-predicted)/mean measured = percent error.

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Table 3.— *Total tree green weight*
(In pounds)

D.b.h. class (in)	Total tree height (feet)							
	40	48	56	64	72	80	88	96
BLACK OAK								
6	273	322	370	417	464	511	556	602
8	510	601	690	779	866	953	1,038	1,123
10	827	975	1,120	1,263	1,405	1,545	1,684	1,822
12	1,227	1,447	1,663	1,876	2,086	2,295	2,501	2,705
14	1,714	2,021	2,323	2,620	2,914	3,205	3,493	3,778
16	2,290	2,700	3,103	3,500	3,893	4,281	4,666	5,047
18	2,956	3,485	4,005	4,518	5,025	5,526	6,023	6,515
20	3,715	4,379	5,033	5,678	6,315	6,945	7,568	8,187
22	4,567	5,384	6,188	6,981	7,764	8,538	[illegible]	10,066
24	5,516	6,502	7,473	8,430	9,376	10,311	11,237	12,155
26	6,561	7,734	8,889	10,027	11,152	12,265	13,367	14,459
RED OAK								
6	208	254	301	349	397	446	496	546
8	404	494	585	678	772	867	963	1,060
10	676	827	980	1,135	1,293	1,452	1,613	1,775
12	1,031	1,260	1,493	1,730	1,970	2,212	2,457	2,704
14	1,471	1,798	2,131	2,469	2,812	3,158	3,507	3,860
16	2,002	2,448	2,901	3,361	3,827	4,298	4,774	5,254
18	2,628	3,213	3,808	4,411	5,023	5,641	6,266	6,897
20	3,352	4,098	4,857	5,626	6,406	7,195	7,992	8,796
22	4,177	5,106	6,052	7,011	7,983	8,966	9,959	10,961
24	5,106	6,243	7,399	8,571	9,759	10,961	12,175	13,400
26	6,143	7,510	8,900	10,311	11,741	13,186	14,646	16,120
WHITE OAK								
6	348	380	409	437	462	486	509	531
8	660	720	776	827	876	921	964	1,006
10	1,083	1,182	1,274	1,358	1,438	1,512	1,583	1,651
12	1,624	1,773	1,910	2,037	2,155	2,268	2,374	2,476
14	2,287	2,497	2,690	2,868	3,036	3,194	3,344	3,487
16	3,077	3,360	3,619	3,859	4,084	4,297	4,499	4,692
18	3,998	4,365	4,701	5,013	5,306	5,583	5,845	6,095
20	5,052	5,516	5,941	6,336	6,706	7,055	7,386	7,703
22	6,243	6,817	7,342	7,830	8,287	8,719	9,129	9,519
24	7,575	8,271	8,908	9,500	10,055	10,578	11,075	11,550
26	9,049	9,880	10,642	11,349	12,012	12,637	13,231	13,798
HICKORY								
6	432	500	566	630	692	753	812	871
8	737	852	964	1,073	1,179	1,283	1,384	1,484
10	1,114	1,289	1,458	1,622	1,783	1,940	2,093	2,244
12	1,562	1,807	2,044	2,275	2,499	2,719	2,935	3,146
14	2,078	2,404	2,720	3,027	3,326	3,618	3,905	4,187
16	2,662	3,080	3,484	3,877	4,260	4,634	5,002	5,362
18	3,311	3,831	4,334	4,822	5,299	5,765	6,222	6,670
20	4,025	4,657	5,268	5,862	6,441	7,008	7,563	8,108
22	4,802	5,556	6,286	6,994	7,686	8,362	9,024	9,675
24	5,642	6,529	7,386	8,218	9,030	9,825	10,603	11,368
26	6,545	7,572	8,566	9,532	10,474	11,396	12,299	13,185
WHITE ASH								
6	278	305	330	353	375	395	415	433
8	530	582	629	673	714	753	790	826
10	875	959	1,037	1,109	1,177	1,242	1,303	1,362
12	1,316	1,443	1,560	1,669	1,772	1,869	1,961	2,049
14	1,860	2,039	2,205	2,359	2,503	2,640	2,771	2,895
16	2,509	2,751	2,974	3,182	3,377	3,562	3,738	3,906
18	3,267	3,582	3,873	4,143	4,398	4,638	4,867	5,086
20	4,137	4,537	4,905	5,247	5,569	5,874	6,164	6,441
22	5,123	5,618	6,073	6,497	6,896	7,274	7,633	7,976
24	6,226	6,828	7,381	7,897	8,382	8,840	9,277	9,694
26	7,450	8,170	8,832	9,449	10,029	10,578	11,100	11,600
YELLOW POPLAR								
6	233	289	347	406	467	529	593	657
8	391	486	583	684	786	891	997	1,106
10	586	728	874	1,024	1,177	1,334	1,494	1,656
12	815	1,012	1,215	1,424	1,637	1,855	2,078	2,303
14	1,078	1,338	1,606	1,882	2,164	2,452	2,746	3,045
16	1,372	1,704	2,045	2,397	2,756	3,123	3,497	3,877
18	1,698	2,108	2,532	2,966	3,411	3,865	4,328	4,798
20	2,055	2,551	3,063	3,589	4,127	4,677	5,237	5,806
22	2,442	3,032	3,640	4,265	4,905	5,558	6,223	6,900
24	2,859	3,549	4,261	4,992	5,741	6,505	7,284	8,076
26	3,304	4,102	4,925	5,771	6,636	7,520	8,420	9,335

Table 4.— *Tree green weight to 2-inch top*
(In pounds)

D.b.h. class (in)	Total tree height (feet)							
	40	48	56	64	72	80	88	96
BLACK OAK								
6	210	252	293	335	377	419	461	503
8	399	479	559	638	718	798	878	957
10	658	789	920	1,052	1,183	1,315	1,446	1,578
12	989	1,187	1,384	1,582	1,779	1,977	2,175	2,372
14	1,396	1,675	1,954	2,233	2,512	2,791	3,070	3,349
16	1,882	2,259	2,635	3,011	3,387	3,763	4,139	4,516
18	2,450	2,940	3,429	3,919	4,409	4,898	5,388	5,877
20	3,101	3,721	4,341	4,961	5,581	6,200	6,820	7,440
22	3,838	4,606	5,373	6,140	6,907	7,674	8,441	9,208
24	4,664	5,596	6,528	7,460	8,392	9,324	10,256	11,188
26	5,578	6,693	7,808	8,923	10,038	11,153	12,267	13,382
RED OAK								
6	208	246	284	321	358	395	431	467
8	403	477	550	622	694	764	835	905
10	673	797	918	1,039	1,158	1,277	1,394	1,511
12	1,024	1,211	1,397	1,580	1,762	1,942	2,120	2,298
14	1,459	1,727	1,991	2,252	2,511	2,767	3,022	3,275
16	1,983	2,347	2,706	3,061	3,413	3,762	4,108	4,451
18	2,600	3,077	3,548	4,013	4,474	4,932	5,385	5,836
20	3,313	3,920	4,520	5,113	5,701	6,283	6,861	7,435
22	4,124	4,880	5,627	6,366	7,097	7,822	8,542	9,257
24	5,037	5,961	6,873	7,775	8,669	9,555	10,434	11,307
26	6,055	7,166	8,262	9,346	10,420	11,485	12,542	13,591
WHITE OAK								
6	296	297	298	298	299	299	300	300
8	604	606	608	609	610	611	612	613
10	1,051	1,054	1,057	1,060	1,062	1,064	1,066	1,067
12	1,652	1,657	1,662	1,666	1,669	1,672	1,675	1,678
14	2,422	2,430	2,436	2,442	2,447	2,452	2,456	2,459
16	3,374	3,384	3,394	3,401	3,408	3,415	3,420	3,426
18	4,519	4,533	4,546	4,556	4,566	4 574	4,582	4,588
20	5,869	5,888	5,904	5,918	5,930	5,941	5,951	5,960
22	7,435	7,459	7,479	7,497	7,512	7,526	7,538	7,550
24	9,227	9,257	9,282	9,303	9,322	9,339	9,355	9,369
26	11,255	11,291	11,321	11,347	11,371	11,392	11,411	11,428
HICKORY								
6	316	362	405	447	488	527	566	603
8	565	647	724	799	872	942	1,011	1,078
10	887	1,014	1,137	1,254	1,368	1,479	1,586	1,691
12	1,281	1,466	1,642	1,812	1,977	2,136	2,292	2,444
14	1,749	2,001	2,241	2,473	2,698	2,916	3,128	3,336
16	2,290	2,619	2,935	3,239	3,533	3,818	4,096	4,368
18	2,904	3,322	3,722	4,108	4,481	4,843	5,195	5,540
20	3,593	4,110	4,605	5,081	5,542	5,990	6,426	6,852
22	4,355	4,981	5,581	6,159	6,718	7,261	7,790	8,306
24	5,191	5,938	6,653	7,341	8 008	8,655	9,285	9,901
26	6,101	6,979	7,819	8,629	9,412	10,172	10,913	11,637
YELLOW POPLAR								
6	121	165	216	272	334	401	473	550
8	205	282	368	464	569	682	805	936
10	310	425	556	700	859	1,031	1,216	1,414
12	435	596	778	981	1,203	1,444	1,703	1,980
14	578	792	1,035	1,304	1,599	1,920	2,264	2,633
16	740	1,014	1,325	1,669	2,047	2,457	2,898	3,370
18	919	1,261	1,647	2,075	2,545	3,055	3,603	4,189
20	1,117	1,532	2,001	2,522	3,092	3,712	4,378	5,090
22	1,332	1,827	2,386	3,007	3,688	4,427	5,221	6,071
24	1,565	2,146	2,803	3,532	4,332	5,199	6,132	7,130
26	1,814	2,488	3,250	4,095	5,022	6,028	7,110	8,267
WHITE ASH								
6	154	201	252	306	363	423	486	552
8	268	349	437	531	631	735	845	959
10	411	536	671	815	968	1,129	1,297	1,472
12	583	761	952	1,157	1,374	1,602	1,841	2,090
14	784	1,023	1,280	1,556	1,847	2,154	2,475	2,810
16	1,013	1,322	1,655	2,010	2,387	2,783	3,198	3,631
18	1,270	1,657	2,075	2,521	2,993	3,490	4,010	4,553
20	1,555	2,029	2,540	3,086	3,664	4,273	4,910	5,574
22	1,868	2,436	3,050	3,706	4,400	5,131	5,896	6,693
24	2,207	2,879	3,605	4,380	5,200	6,064	6,968	7,911
26	2,574	3,358	4,204	5,108	6,064	7,072	8,126	9,225

Table 5.— *Tree green weight to 4-inch top*
(In pounds)

D.b.h. class (in)	Total tree height (feet)							
	40	48	56	64	72	80	88	96
				BLACK OAK				
6	186	220	255	289	323	357	391	425
8	361	428	496	562	629	694	760	825
10	604	717	830	941	1,052	1,163	1,272	1,381
12	920	1,093	1,264	1,434	1,603	1,771	1,938	2,104
14	1,313	1,560	1,805	2,048	2,289	2,529	2,767	3,004
16	1,787	2,124	2,457	2,787	3,116	3,442	3,767	4,090
18	2,346	2,787	3,225	3,659	4,090	4,518	4,944	5,368
20	2,992	3,555	4,113	4,666	5,216	5,763	6,306	6,847
22	3,729	4,430	5,126	5,815	6,500	7,181	7,859	8,532
24	4,559	5,417	6,266	7,110	7,947	8,780	9,608	10,431
26	5,484	6,516	7,539	8,553	9,561	10,562	11,558	12,549
				RED OAK				
6	185	217	248	278	308	337	366	394
8	366	428	489	549	608	665	722	779
10	620	726	829	931	1,030	1,128	1,225	1,320
12	955	1,118	1,277	1,432	1,586	1,736	1,885	2 032
14	1,375	1,609	1,838	2,063	2,283	2,500	2,715	2,926
16	1,886	2,207	2,521	2,829	3,131	3,429	3,723	4,013
18	2,492	2,917	3,331	3,738	4,138	4,531	4,919	5,303
20	3,198	3,742	4,274	4,796	5,309	5,814	6,312	6,804
22	4,006	4,688	5,355	6,009	6,651	7,284	7,908	8,524
24	4,922	5,760	6,579	7,382	8,171	8,949	9,716	10,473
26	5,948	6,961	7,951	8,921	9,875	10,814	11,741	12,656
				WHITE OAK				
6	266	276	285	292	299	306	312	317
8	530	550	567	583	597	609	621	632
10	905	939	969	995	1,019	1,040	1,060	1,079
12	1,402	1,454	1,500	1,540	1,577	1,611	1,642	1,671
14	2,029	2,104	2,170	2,229	2,283	2,331	2,376	2,418
16	2,795	2,899	2,990	3,071	3,144	3,211	3,273	3,331
18	3,707	3,845	3,965	4,073	4,171	4,260	4,342	4,418
20	4,772	4,950	5,105	5,244	5,369	5,484	5,590	5,688
22	5,998	6,221	6,416	6,591	6,748	6,892	7,025	7,149
24	7,389	7,664	7,905	8,120	8,314	8,492	8,655	8,808
26	8,953	9,286	9,578	9,838	10,073	10,288	10,487	10,672
				HICKORY				
6	265	302	338	373	406	439	471	501
8	484	553	618	682	743	802	860	917
10	772	882	987	1,089	1,186	1,281	1,374	1,464
12	1,132	1,293	1,447	1,596	1,739	1,878	2,014	2,146
14	1,564	1,787	2,000	2,205	2,403	2,595	2,782	2,965
16	2,070	2,364	2,646	2,917	3,179	3,434	3,681	3,923
18	2,650	3,027	3,388	3,735	4,070	4,396	4,713	5,022
20	3,305	3,776	4,226	4,659	5,077	5,483	5,879	6,264
22	4,036	4,611	5,161	5,689	6,201	6,697	7,179	7,650
24	4,844	5,534	6,194	6,829	7,442	8,037	8,617	9,182
26	5,730	6,546	7,326	8,077	8,802	9,507	10,192	10,861
				YELLOW POPLAR				
6	111	158	213	276	347	425	511	604
8	183	260	350	453	569	697	838	992
10	268	382	514	665	835	1,024	1,231	1,456
12	367	522	704	911	1,143	1,402	1,685	1,993
14	479	681	918	1,188	1,491	1,828	2,197	2,600
16	603	857	1,155	1,495	1,877	2,300	2,766	3,272
18	738	1,050	1,414	1,831	2,299	2,818	3,388	4,008
20	885	1,259	1,696	2,195	2,756	3,378	4,062	4,805
22	1,043	1,484	1,998	2,587	3,248	3,981	4,786	5,662
24	1,212	1,724	2,322	3,005	3,773	4,625	5,560	6,578
26	1,391	1,978	2,665	3,449	4,331	5,308	6,382	7,550
				WHITE ASH				
6	160	191	222	254	285	315	346	377
8	303	362	421	479	538	596	655	713
10	496	593	689	786	882	977	1,073	1,168
12	743	888	1,032	1,176	1,320	1,464	1,607	1,750
14	1,045	1,249	1,452	1,655	1,857	2,059	2,260	2,461
16	1,404	1,679	1,952	2,224	2,496	2,767	3,038	3,308
18	1,823	2,179	2,533	2,887	3,240	3,592	3,943	4,293
20	2,301	2,751	3,199	3,646	4,091	4,535	4,979	5,421
22	2,842	3,397	3,951	4,502	5,052	5,601	6,149	6,695
24	3,446	4,119	4,790	5,459	6,126	6,791	7,455	8,118
26	4,114	4,918	5,719	6,517	7,313	8,108	8,900	9,692

Table 6.— *Tree oven-dry weight to 2-inch top*
(In pounds)

D.b.h. class (in)	Total tree height (feet)							
	40	48	56	64	72	80	88	96
BLACK OAK								
6	105	126	147	168	189	210	231	252
8	199	239	279	319	359	399	439	479
10	328	394	459	525	591	656	722	788
12	493	592	690	789	888	986	1,085	1,184
14	696	835	974	1,113	1,253	1,392	1,531	1,670
16	937	1,125	1,313	1,500	1,688	1,875	2,063	2,251
18	1,220	1,464	1,708	1,952	2,196	2,440	2,684	2,928
20	1,543	1,852	2,161	2,469	2,778	3,087	3,396	3,705
22	1,909	2,291	2,673	3,055	3,437	3,820	4,202	4,584
24	2,319	2,783	3,247	3,711	4,175	4,639	5,103	5,567
26	2,773	3,328	3,882	4,437	4,992	5,547	6,102	6,657
RED OAK								
6	103	122	141	159	177	195	213	231
8	200	236	272	308	343	378	413	447
10	333	394	454	514	573	631	689	746
12	506	599	690	781	870	959	1,047	1,134
14	721	853	984	1,112	1,240	1,366	1,492	1,616
16	980	1,159	1,336	1,511	1,685	1,856	2,027	2,196
18	1,285	1,519	1,751	1,981	2,208	2,433	2,656	2,878
20	1,636	1,935	2,231	2,523	2,812	3,099	3,383	3,665
22	2,036	2,409	2,776	3,140	3,500	3,857	4,211	4,562
24	2,487	2,941	3,390	3,834	4,274	4,709	5,142	5,571
26	2,988	3,535	4,074	4,608	5,136	5,660	6,179	6,695
WHITE OAK								
6	169	169	169	169	169	169	169	169
8	344	344	344	344	344	344	344	344
10	597	597	597	597	597	597	597	598
12	937	937	937	937	937	938	938	938
14	1,371	1,372	1,372	1,372	1,372	1,372	1,372	1,373
16	1,907	1,908	1,908	1,908	1,909	1,909	1,909	1,909
18	2,552	2,553	2,553	2,553	2,554	2,554	2,554	2,555
20	3,311	3,312	3,312	3,313	3,313	3,314	3,314	3,314
22	4,191	4,192	4,192	4,193	4,194	4,194	4,195	4,195
24	5,196	5,197	5,198	5,199	5,200	5,200	5,201	5,201
26	6,333	6,334	6,335	6,336	6,337	6,338	6,339	6,339
HICKORY								
6	172	197	221	244	267	289	310	331
8	308	353	396	437	477	516	554	591
10	483	553	621	685	748	809	869	927
12	698	799	897	990	1,081	1,169	1,255	1,339
14	953	1,091	1,224	1,352	1,476	1,596	1,713	1,828
16	1,247	1,429	1,602	1,770	1,932	2,090	2,243	2,393
18	1,582	1,812	2,032	2,245	2,450	2,650	2,845	3,036
20	1,957	2,241	2,514	2,777	3,031	3,278	3,519	3,755
22	2,372	2,717	3,047	3,365	3,674	3,974	4,266	4,551
24	2,827	3,238	3,632	4,012	4,379	4,737	5,085	5,425
26	3,323	3,806	4,269	4,715	5,147	5,567	5,976	6,376
WHITE ASH								
6	111	129	146	162	178	194	209	225
8	212	246	278	309	340	370	399	428
10	350	405	458	510	560	609	658	705
12	526	609	689	767	842	917	989	1,061
14	743	860	973	1,083	1,190	1,295	1,397	1,498
16	1,002	1,160	1,312	1,460	1,605	1,746	1,884	2,020
18	1,305	1,510	1,708	1,901	2,089	2,273	2,453	2,630
20	1,652	1,912	2,163	2,407	2,645	2,878	3,106	3,330
22	2,045	2,366	2,677	2,980	3,274	3,563	3,845	4,123
24	2,485	2,876	3,253	3,621	3,979	4,329	4,673	5,010
26	2,973	3,440	3,892	4,332	4,760	5,179	5,590	5,994
YELLOW POPLAR								
6	62	85	111	139	171	205	241	280
8	105	144	188	237	290	348	410	477
10	159	218	284	358	439	526	620	720
12	223	305	398	501	614	737	868	1,008
14	297	406	530	667	817	979	1,154	1,341
16	379	520	678	853	1,045	1,253	1,477	1,716
18	472	646	842	1,061	1,299	1,558	1,836	2,133
20	573	785	1,024	1,288	1,578	1,893	2,231	2,592
22	683	936	1,221	1,537	1,882	2,257	2,660	3,091
24	803	1,099	1,434	1,804	2,211	2,651	3,124	3,630
26	931	1,274	1,662	2,092	2,563	3,073	3,622	4,208

Table 7.— *Tree oven-dry weight to 4-inch top*
(In pounds)

D.b.h. class (in)	Total tree height (feet)							
	40	48	56	64	72	80	88	96
BLACK OAK								
6	93	110	128	145	162	179	196	213
8	180	214	248	281	315	348	381	413
10	302	358	415	471	526	581	636	691
12	459	546	631	716	801	885	969	1,052
14	655	778	901	1,022	1,143	1,262	1,382	1,500
16	891	1,059	1,225	1,390	1,554	1,717	1,879	2,041
18	1,168	1,389	1,607	1,823	2,039	2,253	2,465	2,677
20	1,489	1,770	2,048	2,324	2,599	2,871	3,143	3,413
22	1,855	2,205	2,551	2,895	3,237	3,577	3,914	4,251
24	2,267	2,694	3,118	3,538	3,955	4,370	4,783	5,194
26	2,726	3,240	3,749	4,254	4,757	5,256	5,752	6,246
RED OAK								
6	92	108	123	138	153	167	181	196
8	181	212	242	272	301	330	358	386
10	307	360	411	461	510	558	606	653
12	473	553	632	709	784	859	932	1,005
14	680	796	909	1,020	1,129	1,236	1,341	1,446
16	933	1,091	1,246	1,398	1,547	1,694	1,839	1,982
18	1,232	1,441	1,646	1,846	2,043	2,237	2,428	2,617
20	1,580	1,848	2,110	2,367	2,620	2,869	3,114	3,357
22	1,978	2,314	2,643	2,965	3,281	3,593	3,900	4,204
24	2,429	2,842	3,246	3,641	4,030	4,413	4,790	5,163
26	2,935	3,434	3,921	4,399	4,868	5,331	5,787	6,237
WHITE OAK								
6	147	155	161	166	171	176	180	184
8	291	304	317	328	338	347	355	363
10	492	515	536	555	572	587	602	615
12	756	792	824	853	879	903	925	946
14	1,088	1,139	1,185	1,226	1,264	1,298	1,330	1,360
16	1,490	1,561	1,624	1,680	1,732	1,779	1,823	1,863
18	1,967	2,061	2,144	2,218	2,286	2,348	2,406	2,460
20	2,522	2,642	2,748	2,844	2,931	3,011	3,085	3,154
22	3,158	3,308	3,441	3,561	3,669	3,769	3,862	3,949
24	3,877	4,062	4,225	4,371	4,505	4,628	4,742	4,848
26	4,683	4,906	5,103	5,280	5,441	5,589	5,727	5,855
HICKORY								
6	146	166	187	206	225	243	260	278
8	266	304	341	376	410	443	476	507
10	424	485	543	600	654	707	759	809
12	621	710	796	878	958	1,036	1,111	1,185
14	857	981	1,099	1,213	1,323	1,430	1,534	1,636
16	1,133	1,297	1,453	1,604	1,749	1,891	2,029	2,163
18	1,450	1,859	1,859	2,052	2,238	2,419	2,596	2,768
20	1,808	2,068	2,318	2,558	2,790	3,016	3,236	3,451
22	2,207	2,525	2,829	3,123	3,406	3,682	3,950	4,213
24	2,648	3,029	3,394	3,746	4,087	4,417	4,739	5,054
26	3,130	3,582	4,013	4,429	4,832	5,223	5,604	5,975
WHITE ASH								
6	93	111	130	148	167	185	204	222
8	174	209	244	279	314	348	383	418
10	285	342	398	455	512	569	626	683
12	425	510	595	680	765	849	934	1,019
14	596	715	835	954	1,073	1,192	1,311	1,430
16	800	959	1,119	1,279	1,439	1,598	1,758	1,918
18	1,036	1,243	1,450	1,657	1,864	2,071	2,278	2,484
20	1,306	1,567	1,828	2,089	2,349	2,610	2,871	3,132
22	1,610	1,932	2,253	2,575	2,897	3,218	3,540	3,862
24	1,949	2,339	2,728	3,118	3,507	3,897	4,286	4,675
26	2,324	2,789	3,253	3,717	4,182	4,646	5,110	5,574
YELLOW POPLAR								
6	55	78	106	137	172	211	254	301
8	90	128	173	225	282	346	417	493
10	132	188	254	329	414	508	611	724
12	181	258	348	451	566	695	836	990
14	236	336	453	587	738	906	1,090	1,291
16	297	423	570	739	929	1,140	1,371	1,624
18	363	517	698	905	1,137	1,395	1,679	1,988
20	435	620	837	1,084	1,363	1,672	2,012	2,383
22	513	731	986	1,277	1,605	1,970	2,370	2,807
24	595	848	1,144	1,483	1,864	2,288	2,753	3,259
26	683	974	1,313	1,702	2,139	2,625	3,158	3,740

Table 8.— *Tree volume to 2-inch top*
(In cubic feet)

D.b.h. class (in)	Total tree height (feet) 40	48	56	64	72	80	88	96
				BLACK OAK				
6	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.5
8	5.1	6.1	7.2	8.2	9.2	10.2	11.3	12.3
10	8.4	10.0	11.7	13.4	15.1	16.8	13.5	20.1
12	12.5	15.0	17.6	20.1	22.6	25.1	27.6	30.1
14	17.6	21.2	24.7	28.2	31.8	35.3	38.9	42.4
16	23.7	28.4	33.2	37.9	42.7	47.5	52.2	57.0
18	30.7	36.9	43.1	49.3	55.4	61.6	67.8	74.0
20	38.8	46.6	54.4	62.2	70.0	77.8	85.6	93.4
22	47.9	57.5	67.2	76.8	86.4	96.1	105.7	115.4
24	58.1	69.8	81.4	93.1	104.8	116.5	128.2	139.9
26	69.4	83.3	97.2	111.2	125.1	139.1	153.1	167.0
				RED OAK				
6	2.7	3.2	3.7	4.1	4.6	5.1	5.5	6.0
8	5.2	6.1	7.0	8.0	8.9	9.8	10.7	11.5
10	8.6	10.2	11.7	13.3	14.8	16.3	17.7	19.2
12	13.1	15.5	17.8	20.1	22.4	24.7	26.9	29.1
14	18.6	22.0	25.3	28.6	31.9	35.1	38.3	41.4
16	25.3	29.8	34.4	38.8	43.2	47.6	51.9	56.2
18	33.1	39.1	45.0	50.8	56.6	62.3	68.0	73.6
20	42.1	49.7	57.2	64.6	72.0	79.3	86.5	93.7
22	52.3	61.8	71.1	80.4	89.5	98.6	107.5	116.5
24	63.8	75.4	86.8	98.1	109.2	120.3	131.2	142.1
26	76.6	90.5	104.2	117.7	131.1	144.4	157.6	170.6
				WHITE OAK				
6	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.3
8	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.6
10	13.7	13.9	14.1	14.2	14.4	14.5	14.6	14.7
12	21.1	21.5	21.7	22.0	22.2	22.4	22.6	22.7
14	30.6	31.0	31.4	31.8	32.1	32.4	32.6	32.9
16	42.1	42.7	43.3	43.8	44.2	44.6	44.9	45.3
18	55.8	56.6	57.4	58.0	58.6	59.1	59.5	60.0
20	71.8	72.9	73.8	74.6	75.4	76.0	76.6	77.2
22	90.2	91.5	92.7	93.7	94.7	95.5	96.2	96.9
24	111.0	112.7	114.2	115.4	116.6	117.6	118.5	119.4
26	134.4	136.5	138.2	139.8	141.2	142.4	143.5	144.6
				HICKORY				
6	3.8	4.4	4.9	5.4	5.9	6.4	6.9	7.3
8	6.8	7.8	8.8	9.7	10.6	11.5	12.3	13.1
10	10.7	12.3	13.8	15.2	16.6	18.0	19.3	20.6
12	15.5	17.8	19.9	22.0	24.0	26.0	27.9	29.8
14	21.2	24.3	27.2	30.1	32.8	35.5	38.1	40.7
16	27.7	31.8	35.6	39.4	43.0	46.5	49.9	53.3
18	35.2	40.3	45.2	49.9	54.5	59.0	63.3	67.6
20	43.5	49.8	55.9	61.8	67.5	73.0	78.4	83.6
22	52.7	60.4	67.8	74.9	81.8	88.5	95.0	101.4
24	62.9	72.0	80.8	89.3	97.5	105.5	113.2	120.8
26	73.9	84.7	95.0	104.9	114.6	124.0	133.1	142.0
				WHITE ASH				
6	3.0	3.5	3.9	4.4	4.9	5.3	5.8	6.2
8	5.6	6.5	7.4	8.3	9.2	10.0	10.9	11.7
10	9.2	10.7	12.2	13.6	15.1	16.5	17.8	19.2
12	13.8	16.0	18.3	20.4	22.6	24.7	26.7	28.8
14	19.4	22.6	25.7	28.8	31.8	34.7	37.6	40.5
16	26.0	30.4	34.6	38.7	42.7	46.7	50.6	54.4
18	33.8	39.4	44.9	50.2	55.5	60.6	65.7	70.6
20	42.7	49.8	56.7	63.4	70.0	76.5	82.9	89.2
22	52.7	61.5	70.0	78.3	86.5	94.5	102.4	110.2
24	64.0	74.6	84.9	95.0	104.9	114.6	124.2	133.7
26	76.4	89.1	101.4	113.5	125.3	136.9	148.3	159.6
				YELLOW POPLAR				
6	2.0	2.8	3.7	4.7	5.8	6.9	8.2	9.6
8	3.4	4.7	6.2	7.9	9.7	11.7	13.9	16.2
10	5.1	7.1	9.3	11.8	14.6	17.6	20.8	24.3
12	7.1	9.8	13.0	16.5	20.3	24.5	29.0	33.9
14	9.4	13.0	17.2	21.8	26.9	32.4	38.4	44.9
16	12.0	16.6	21.9	27.8	34.2	41.3	49.0	57.2
18	14.9	20.6	27.1	34.4	42.4	51.2	60.7	70.9
20	18.0	24.9	32.8	41.6	51.4	62.0	73.5	85.8
22	21.4	29.6	39.0	49.5	61.1	73.7	87.4	102.0
24	25.1	34.7	45.7	58.0	71.6	86.4	102.4	119.5
26	29.0	40.2	52.9	67.1	82.8	99.9	118.4	138.3

Table 9. — *Tree volume to 4-inch top*
(In cubic feet)

D.b.h. class (in)	Total tree height (feet)							
	40	48	56	64	72	80	88	96
				BLACK OAK				
6	2.4	2.9	3.3	3.8	4.2	4.6	5.1	5.5
8	4.6	5.5	6.4	7.2	8.1	8.9	9.8	10.6
10	7.7	9.1	10.6	12.0	13.4	14.9	16.3	17.7
12	11.6	13.8	16.0	18.2	20.4	22.5	24.7	26.8
14	16.5	19.6	22.8	25.9	28.9	32.0	35.1	38.1
16	22.4	26.6	30.9	35.1	39.2	43.4	47.5	51.6
18	29.3	34.8	40.4	45.8	51.3	56.7	62.1	67.5
20	37.2	44.3	51.3	58.3	65.2	72.1	79.0	85.9
22	46.2	55.0	63.7	72.4	81.0	89.6	98.2	106.7
24	56.3	67.1	77.7	88.3	98.8	109.3	119.7	130.1
26	67.6	80.5	93.3	105.9	118.6	131.1	143.6	156.1
				RED OAK				
6	2.4	2.8	3.2	3.6	4.0	4.3	4.7	5.1
8	4.7	5.5	6.3	7.0	7.8	8.5	9.2	10.0
10	8.0	9.3	10.6	11.9	13.1	14.4	15.6	16.8
12	12.2	14.3	16.3	18.2	20.2	22.1	23.9	25.8
14	17.5	20.5	23.4	26.2	29.0	31.7	34.4	37.0
16	24.0	28.0	32.0	35.8	39.6	43.4	47.1	50.7
18	31.6	37.0	42.2	47.3	52.3	57.2	62.1	66.8
20	40.5	47.3	54.0	60.5	66.9	73.3	79.5	85.6
22	50.6	59.2	67.5	75.7	83.7	91.6	99.4	107.1
24	62.1	72.6	82.8	92.9	102.7	112.4	121.9	131.4
26	75.0	87.6	100.0	112.1	124.0	135.6	147.2	158.5
				WHITE OAK				
6	3.6	3.8	3.9	4.0	4.2	4.3	4.4	4.5
8	7.1	7.4	7.7	8.0	8.2	8.4	8.6	8.8
10	12.0	12.5	13.0	13.5	13.9	14.3	14.6	15.0
12	18.4	19.2	20.0	20.7	21.4	21.9	22.5	23.0
14	26.4	27.7	28.8	29.8	30.7	31.6	32.3	33.1
16	36.2	37.9	39.5	40.8	42.1	43.2	44.3	45.3
18	47.8	50.1	52.1	53.9	55.6	57.1	58.5	59.8
20	61.2	64.2	66.8	69.1	71.2	73.2	75.0	76.7
22	76.7	80.3	83.6	86.5	89.2	91.6	93.9	96.0
24	94.1	98.6	102.6	106.2	109.5	112.5	115.3	117.9
26	113.7	119.1	123.9	128.3	132.2	135.8	139.2	142.3
				HICKORY				
6	3.3	3.7	4.2	4.6	5.0	5.4	5.8	6.2
8	5.9	6.8	7.6	8.4	9.2	9.9	10.6	11.3
10	9.5	10.8	12.1	13.4	14.6	15.8	16.9	18.1
12	13.9	15.9	17.8	19.6	21.4	23.1	24.8	26.5
14	19.1	21.9	24.5	27.1	29.5	31.9	34.3	36.5
16	25.3	28.9	32.4	35.8	39.1	42.2	45.3	48.3
18	32.4	37.0	41.5	45.8	50.0	54.0	57.9	61.8
20	40.3	46.1	51.7	57.1	62.3	67.3	72.2	77.0
22	49.2	56.3	63.1	69.7	76.0	82.2	88.2	94.0
24	59.1	67.6	75.7	83.6	91.2	98.6	105.8	112.8
26	69.8	79.9	89.5	98.8	107.8	116.5	125.0	133.3
				WHITE ASH				
6	2.5	3.0	3.5	4.0	4.6	5.1	5.6	6.1
8	4.7	5.6	6.6	7.6	8.5	9.5	10.5	11.5
10	7.6	9.2	10.7	12.3	13.9	15.5	17.1	18.7
12	11.3	13.6	16.0	18.3	20.7	23.0	25.4	27.7
14	15.8	19.1	22.3	25.6	28.9	32.2	35.5	38.8
16	21.2	25.5	29.9	34.2	38.6	43.0	47.5	51.9
18	27.3	33.0	38.6	44.3	49.9	55.6	61.3	67.0
20	34.4	41.4	48.5	55.7	62.8	70.0	77.1	84.3
22	42.3	51.0	59.7	68.5	77.3	86.1	94.9	103.8
24	51.1	61.6	72.2	82.8	93.4	104.0	114.7	125.4
26	60.9	73.4	85.9	98.5	111.2	123.9	136.6	149.3
				YELLOW POPLAR				
6	1.8	2.6	3.6	4.6	5.9	7.2	8.7	10.3
8	3.0	4.3	5.8	7.6	9.6	11.8	14.2	16.9
10	4.4	6.3	8.5	11.1	14.0	17.2	20.8	24.7
12	6.0	8.6	11.6	15.1	19.1	23.5	28.4	33.7
14	7.8	11.1	15.1	19.7	24.8	30.6	36.9	43.9
16	9.8	14.0	19.0	24.7	31.2	38.4	46.4	55.1
18	11.9	17.1	23.2	30.2	38.1	46.9	56.7	67.3
20	14.3	20.5	27.8	36.1	45.6	56.2	67.8	80.6
22	16.8	24.1	32.7	42.5	53.7	66.1	79.8	94.8
24	19.5	27.9	37.9	49.3	62.2	76.7	92.5	109.9
26	22.3	32.0	43.4	56.5	71.3	87.9	106.1	126.0

Table 10.— *Total tree green weight*
(In kilograms)

D.b.h. class (cm)	Total tree height (meters)						
	12	15	18	21	24	27	30
BLACK OAK							
15	118	144	170	196	221	245	270
20	220	269	317	365	412	458	503
25	357	437	515	592	668	743	817
30	530	649	765	879	991	1,102	1,212
35	741	906	1,068	1,227	1,385	1,540	1,694
40	989	1,210	1,427	1,640	1,850	2,057	2,262
45	1,277	1,562	1,842	2,116	2,388	2,655	2,920
50	1,605	1,963	2,314	2,660	3,000	3,337	3,670
55	1,973	2,413	2,845	3,270	3,689	4,103	4,512
60	2,383	2,915	3,436	3,949	4,455	4,954	5,448
RED OAK							
15	89	114	140	166	192	218	245
20	174	222	271	322	373	424	477
25	291	372	454	539	624	710	798
30	443	566	692	820	951	1,082	1,216
35	632	808	988	1,171	1,357	1,545	1,735
40	860	1,100	1,345	1,594	1,847	2,103	2,362
45	1,129	1,444	1,765	2,092	2,424	2,760	3,100
50	1 440	1,842	2,252	2,669	3,092	3,520	3,953
55	1,795	2,295	2,806	3,325	3,853	4,387	4,927
60	2,194	2,806	3,430	4,065	4,710	5,363	6,023
WHITE OAK							
15	151	168	184	198	211	224	235
20	287	319	348	375	400	424	446
25	471	524	572	616	657	696	732
30	706	786	858	924	985	1,043	1,097
35	994	1,107	1,208	1,301	1,388	1,469	1,545
40	1,337	1,489	1,626	1,751	1,867	1,976	2,079
45	1,737	1,934	2,112	2,275	2,426	2,568	2,701
50	2,195	2,444	2,669	2,875	3,066	3,245	3,414
55	2,713	3,021	3,298	3,553	3,789	4,010	4,219
60	3,292	3,665	4,002	4,310	4,597	4,865	5,119
HICKORY							
15	188	225	260	294	327	360	391
20	320	383	443	501	558	613	667
25	484	579	670	758	844	927	1,008
30	679	812	939	1,063	1,183	1,299	1,414
35	904	1,080	1,250	1,414	1,574	1,729	1,881
40	1,157	1,384	1,601	1,811	2,015	2,215	2,409
45	1,440	1,721	1,992	2,253	2 507	2,755	2,997
50	1,750	2,092	2,421	2,739	3,048	3,349	3,643
55	2,088	2,497	2,889	3,268	3,636	3,996	4,347
60	2,454	2,933	3,394	3,840	4,273	4,695	5,108
WHITE ASH							
15	121	135	148	160	172	182	192
20	230	258	283	306	327	347	366
25	380	425	466	504	539	572	604
30	572	640	702	759	811	861	908
35	808	904	991	1,072	1,147	1,217	1,283
40	1,089	1,219	1,337	1,446	1,547	1,642	1,731
45	1,419	1,588	1,741	1,883	2,014	2,138	2,255
50	1,797	2,011	2,205	2,384	2,551	2,707	2,856
55	2,225	2,490	2,731	2,952	3,158	3,352	3,536
60	2,704	3,027	3,319	3,588	3,839	4,074	4,297
YELLOW POPLAR							
15	101	131	163	195	229	263	298
20	169	221	274	329	385	443	502
25	254	330	410	492	577	663	752
30	353	460	570	685	803	923	1,046
35	466	607	754	905	1,061	1,220	1,382
40	594	773	960	1,153	1,351	1,553	1,760
45	735	957	1,188	1,427	1,672	1,922	2,178
50	889	1,158	1,438	1,727	2,023	2,326	2,636
55	1,056	1,376	1,709	2,052	2,404	2,764	3,132
60	1,236	1,611	2,000	2,402	2,814	3,236	3,667

Table 11.— *Tree green weight to 5-centimeter top*
(In kilograms)

D.b.h. class (cm)	Total tree height (meters)						
	12	15	18	21	24	27	30
BLACK OAK							
15	90	113	135	158	181	203	226
20	172	215	258	301	344	387	430
25	283	354	425	496	566	637	708
30	426	533	639	745	852	958	1,065
35	602	752	902	1,052	1,203	1,353	1,503
40	811	1,014	1,216	1,419	1,622	1,824	2,027
45	1,056	1,319	1,583	1,847	2,111	2,374	2,638
50	1,336	1,670	2,004	2,338	2,672	3,005	3,339
55	1,654	2,067	2,480	2,894	3,307	3,720	4,133
60	2,009	2,511	3,014	3,515	4,017	4,519	5,021
RED OAK							
15	90	110	130	150	170	190	209
20	174	213	253	291	329	367	405
25	290	357	422	486	550	613	676
30	441	542	642	740	837	933	1,028
35	629	773	914	1,054	1,193	1,330	1,466
40	855	1,050	1,243	1,433	1,621	1,807	1,992
45	1,121	1,377	1,630	1,879	2,125	2,370	2,612
50	1,428	1,754	2,076	2,394	2,708	3,019	3,328
55	1,777	2,184	2,585	2,980	3,371	3,759	4,143
60	2,171	2,668	3,157	3,640	4,118	4,591	5,060
WHITE OAK							
15	129	129	130	130	131	131	131
20	263	264	265	266	267	267	268
25	458	460	461	463	464	465	466
30	720	723	725	727	729	731	732
35	1,056	1,060	1,063	1,066	1,069	1,071	1,073
40	1,471	1,477	1,481	1,485	1,489	1,492	1,494
45	1,970	1,978	1,984	1,989	1,994	1,998	2,002
50	2,559	2,569	2,577	2,584	2,590	2,595	2,600
55	3,242	3,254	3,265	3,273	3,281	3,288	3,294
60	4,023	4,038	4,051	4,062	4,072	4,080	4,088
HICKORY							
15	137	162	185	207	229	250	270
20	245	289	331	371	409	446	482
25	385	454	519	582	642	700	757
30	556	656	750	841	928	1,012	1,093
35	759	895	1,024	1,147	1,266	1,381	1,493
40	994	1,172	1,341	1,502	1,658	1,808	1,954
45	1,261	1,487	1,701	1,905	2,103	2,293	2,479
50	1,560	1,839	2,104	2,357	2,601	2,837	3,066
55	1,891	2,229	2,550	2,857	3,153	3,439	3,717
60	2,254	2,657	3,039	3,405	3,758	4,099	4,430
WHITE ASH							
15	66	92	120	150	182	216	252
20	115	159	208	260	316	375	438
25	177	245	319	399	485	576	672
30	251	347	453	567	689	818	954
35	337	467	609	762	926	1,099	1,282
40	436	603	787	985	1,197	1,421	1,657
45	546	756	986	1,235	1,500	1,782	2,077
50	669	926	1,208	1,512	1,837	2,181	2,543
55	803	1,112	1,450	1,816	2,206	2,619	3,054
60	949	1,314	1,714	2,146	2,607	3,095	3,609
YELLOW POPLAR							
15	52	76	104	136	172	211	253
20	88	130	178	232	292	359	430
25	133	196	268	350	442	542	650
30	186	274	376	491	619	759	911
35	248	364	500	653	823	1,009	1,211
40	317	466	640	836	1,053	1,291	1,550
45	394	580	795	1,039	1,309	1,605	1,927
50	479	705	966	1,262	1,591	1,951	2,341
55	571	840	1,152	1,505	1,897	2,326	2,792
60	671	987	1,354	1,768	2,228	2,732	3,279

Table 12.— *Tree green weight to 10-centimeter top*
(In kilograms)

BLACK OAK

D.b.h. class (cm)	Total tree height (meters)						
	12	15	18	21	24	27	30
15	80	99	117	136	154	172	190
20	155	192	228	264	299	334	369
25	260	321	382	441	501	560	618
30	396	489	581	672	763	853	942
35	566	698	830	960	1,089	1,218	1,345
40	770	951	1,130	1,307	1,483	1,657	1,831
45	1,011	1,248	1,483	1,715	1,946	2,175	2,403
50	1,289	1,592	1,891	2,188	2,482	2,775	3,065
55	1,606	1,984	2,357	2,727	3,093	3,458	3,820
60	1,964	2,425	2,881	3,333	3,782	4,227	4,670
RED OAK							
15	80	97	113	129	145	161	176
20	158	191	224	256	287	317	348
25	267	324	379	433	486	538	589
30	412	499	584	667	748	828	907
35	593	718	841	960	1,078	1,193	1,306
40	813	985	1,153	1,317	1,478	1,636	1,791
45	1,074	1,302	1,524	1,740	1,953	2,161	2,367
50	1,378	1,670	1,955	2,233	2,505	2,773	3,037
55	1,726	2,093	2,449	2,798	3,139	3,475	3,805
60	2,121	2,571	3,009	3,437	3,856	4,269	4,675
WHITE OAK							
15	116	121	126	130	133	136	139
20	231	241	250	258	265	272	277
25	394	412	427	441	453	464	474
30	610	638	662	683	701	718	733
35	883	924	958	988	1,015	1,039	1,061
40	1,216	1,272	1,319	1,361	1,398	1,431	1,462
45	1,613	1,687	1,750	1,805	1,854	1,898	1,939
50	2,077	2,172	2,253	2,324	2,387	2,444	2,496
55	2,611	2,730	2,832	2,921	3,000	3,072	3,137
60	3,216	3,364	3,489	3,598	3,696	3,784	3,865
HICKORY							
15	115	135	154	173	190	207	224
20	210	247	282	316	348	379	410
25	335	394	450	504	556	606	654
30	491	578	660	739	815	888	959
35	678	798	912	1,021	1,125	1,227	1,325
40	898	1,056	1,207	1,351	1,489	1,623	1,753
45	1,149	1,353	1,545	1,729	1,907	2,078	2,244
50	1,433	1,687	1,927	2,157	2,378	2,592	2,799
55	1,750	2,060	2,354	2,634	2,904	3,165	3,418
60	2,101	2,473	2,825	3,162	3,486	3,799	4,103
WHITE ASH							
15	69	86	103	119	136	153	169
20	130	162	194	226	257	289	320
25	214	266	318	370	421	473	524
30	320	398	476	554	631	708	785
35	450	560	670	779	888	996	1,104
40	605	753	900	1,047	1,193	1,339	1,484
45	786	978	1,169	1,359	1,549	1,738	1,927
50	992	1,235	1,476	1,716	1,956	2,195	2,433
55	1,225	1,525	1,822	2,119	2,415	2,710	3,005
60	1,486	1,848	2,210	2,569	2,928	3,286	3,643
YELLOW POPLAR							
15	48	73	104	140	182	228	280
20	78	120	171	231	298	375	459
25	115	177	251	339	438	550	674
30	157	242	344	463	600	753	923
35	205	315	449	604	782	982	1,204
40	258	397	565	761	985	1,236	1,515
45	316	486	692	932	1,206	1,514	1,856
50	379	583	829	1,117	1,446	1,816	2,226
55	446	687	977	1,317	1,704	2,140	2,623
60	519	798	1,135	1,529	1,980	2,485	3,047

Table 13.— *Tree oven-dry weight to 5-centimeter top*
(In kilograms)

D.b.h. class (cm)	Total tree height (meters)						
	12	15	18	21	24	27	30
BLACK OAK							
15	45	56	68	79	90	102	113
20	86	107	129	150	172	193	215
25	141	177	212	247	283	318	354
30	212	266	319	372	425	478	531
35	300	375	450	525	600	675	750
40	404	505	606	707	808	909	1,010
45	526	657	788	920	1,051	1,183	1,314
50	665	831	998	1,164	1,330	1,497	1,663
55	823	1,028	1,234	1,440	1,646	1,852	2,058
60	999	1,249	1,499	1,749	1,999	2,249	2,499
RED OAK							
15	44	55	65	74	84	94	103
20	86	106	125	144	163	182	200
25	144	176	209	240	272	303	334
30	218	268	317	365	413	461	508
35	311	382	452	521	589	656	723
40	422	519	614	707	800	892	983
45	554	680	804	927	1,049	1,169	1,288
50	705	866	1,025	1,181	1,336	1,489	1,640
55	878	1,078	1,275	1,470	1,662	1,853	2,042
60	1,072	1,316	1,557	1,795	2,030	2,263	2,493
WHITE OAK							
15	74	74	74	74	74	74	74
20	150	150	150	150	150	150	150
25	260	260	260	261	261	261	261
30	409	409	409	409	409	409	409
35	598	598	598	598	599	599	599
40	832	832	832	832	833	833	833
45	1,113	1,113	1,114	1,114	1,114	1,114	1,114
50	1,444	1,445	1,445	1,445	1,445	1,445	1,446
55	1,828	1,828	1,829	1,829	1,829	1,829	1,830
60	2,266	2,267	2,267	2,268	2,268	2,268	2,269
HICKORY							
15	75	88	101	113	125	137	148
20	134	158	181	203	224	244	264
25	210	248	284	318	351	384	415
30	303	358	410	460	508	554	599
35	414	488	559	627	693	756	818
40	541	639	732	821	907	990	1,071
45	687	811	929	1,042	1,151	1,256	1,359
50	850	1,003	1,149	1,289	1,423	1,554	1,680
55	1,030	1,216	1,393	1,562	1,725	1,883	2,037
60	1,227	1,449	1,660	1,862	2,056	2,245	2,428
WHITE ASH							
15	48	58	67	75	84	92	100
20	92	110	127	144	160	176	191
25	151	181	209	237	263	289	315
30	227	272	315	356	396	435	474
35	321	384	444	503	560	615	669
40	433	518	599	678	755	829	902
45	564	674	780	883	982	1,080	1,175
50	714	854	988	1,118	1,244	1,367	1,487
55	884	1,057	1,223	1,384	1,540	1,692	1,841
60	1,074	1,284	1,486	1,681	1,871	2,056	2,237
YELLOW POPLAR							
15	27	39	53	70	88	107	129
20	45	66	91	119	149	183	219
25	68	100	137	179	225	276	331
30	96	140	192	251	316	387	464
35	127	187	256	333	420	514	617
40	163	239	327	427	537	658	789
45	202	297	407	530	668	818	981
50	246	361	494	644	811	994	1,192
55	293	430	589	769	967	1,185	1,421
60	344	505	692	903	1,136	1,392	1,669

Table 14.— Tree oven-dry weight to 10-centimeter top (In kilograms)

D.b.h. class (cm)	Total tree height (meters)						
	12	15	18	21	24	27	30
BLACK OAK							
15	40	49	59	68	77	86	95
20	78	96	114	132	150	167	185
25	130	161	191	221	250	280	309
30	198	244	290	336	381	426	471
35	282	348	414	479	544	608	672
40	384	474	563	652	740	827	914
45	503	622	739	855	970	1,085	1,199
50	642	793	942	1,090	1,237	1,383	1,528
55	799	987	1,173	1,358	1,541	1,723	1,903
60	977	1,206	1,434	1,659	1,883	2,105	2,326
RED OAK							
15	40	48	56	64	72	80	87
20	78	95	111	127	142	157	172
25	132	161	188	214	241	266	292
30	204	247	289	330	370	410	448
35	293	355	416	475	533	589	645
40	402	487	570	651	730	808	885
45	531	643	753	859	964	1,067	1,168
50	681	825	965	1,102	1,236	1,368	1,498
55	853	1,033	1,209	1,380	1,549	1,714	1,877
60	1,047	1,269	1,485	1,695	1,902	2,105	2,305
WHITE OAK							
15	64	68	71	74	77	79	81
20	126	134	140	146	151	156	160
25	214	227	237	247	256	263	270
30	329	348	365	380	393	405	416
35	473	501	525	546	565	582	598
40	648	687	719	748	774	798	819
45	856	906	950	988	1,022	1,053	1,082
50	1,098	1,162	1,217	1,266	1,310	1,350	1,387
55	1,374	1,455	1,524	1,585	1,640	1,690	1,736
60	1,687	1,786	1,871	1,946	2,014	2,075	2,132
HICKORY							
15	63	74	85	95	105	115	124
20	115	136	155	174	192	210	227
25	184	217	248	278	307	335	362
30	269	317	363	407	449	490	530
35	372	438	501	562	620	676	731
40	491	580	663	743	820	894	967
45	629	742	848	951	1,049	1,145	1,237
50	784	924	1,058	1,185	1,308	1,427	1,542
55	957	1,128	1,291	1,447	1,597	1,742	1,883
60	1,148	1,354	1,549	1,736	1,916	2,090	2,259
WHITE ASH							
15	40	50	60	70	80	90	100
20	75	94	113	131	150	169	188
25	123	153	184	215	245	276	307
30	183	229	275	320	366	412	458
35	257	321	386	450	514	578	642
40	345	431	517	603	689	775	861
45	447	558	670	781	893	1,004	1,116
50	563	704	844	985	1,125	1,266	1,407
55	694	868	1,041	1,214	1,388	1,561	1,734
60	840	1,050	1,260	1,470	1,680	1,890	2,100
YELLOW POPLAR							
15	24	36	52	70	90	114	139
20	39	60	85	114	148	186	229
25	57	87	124	168	217	273	335
30	77	119	170	230	297	374	459
35	101	156	222	299	388	487	598
40	127	196	279	376	488	613	752
45	155	240	342	461	597	751	921
50	186	287	409	552	716	900	1,104
55	219	338	482	651	843	1,060	1,300
60	255	393	560	755	979	1,231	1,510

Table 15.— *Tree volume to 5-centimeter top*

(In kilograms)

D.b.h. class (cm)	Total tree height (meters)						
	12	15	18	21	24	27	30
			BLACK OAK				
15	0.07	0.09	0.11	0.13	0.15	0.16	0.18
20	0.14	0.17	0.21	0.24	0.28	0.31	0.34
25	0.23	0.28	0.34	0.39	0.45	0.51	0.56
30	0.34	0.42	0.51	0.59	0.68	0.76	0.85
35	0.47	0.59	0.71	0.83	0.95	1.07	1.19
40	0.64	0.80	0.96	1.12	1.28	1.44	1.60
45	0.83	1.03	1.24	1.45	1.66	1.87	2.07
50	1.04	1.31	1.57	1.83	2.09	2.36	2.62
55	1.29	1.61	1.94	2.26	2.59	2.91	3.23
60	1.56	1.96	2.35	2.74	3.14	3.53	3.92
			RED OAK				
15	0.07	0.09	0.10	0.12	0.14	0.15	0.17
20	0.14	0.17	0.20	0.23	0.26	0.29	0.32
25	0.23	0.28	0.34	0.39	0.44	0.49	0.54
30	0.35	0.43	0.51	0.59	0.66	0.74	0.81
35	0.50	0.61	0.73	0.84	0.94	1.05	1.16
40	0.68	0.83	0.98	1.13	1.28	1.43	1.57
45	0.89	1.09	1.29	1.48	1.68	1.87	2.06
50	1.13	1.39	1.64	1.89	2.13	2.38	2.62
55	1.41	1.73	2.04	2.35	2.65	2.96	3.25
60	1.72	2.11	2.49	2.86	3.24	3.61	3.97
			WHITE OAK				
15	0.11	0.11	0.11	0.11	0.12	0.12	0.12
20	0.22	0.22	0.23	0.23	0.23	0.23	0.24
25	0.37	0.38	0.38	0.39	0.39	0.40	0.40
30	0.58	0.59	0.60	0.60	0.61	0.62	0.62
35	0.83	0.85	0.86	0.87	0.88	0.89	0.90
40	1.15	1.17	1.19	1.20	1.21	1.23	1.24
45	1.52	1.55	1.57	1.59	1.61	1.62	1.64
50	1.95	1.99	2.02	2.05	2.07	2.09	2.11
55	2.45	2.50	2.54	2.57	2.60	2.63	2.65
60	3.02	3.08	3.13	3.17	3.20	3.23	3.26
			HICKORY				
15	0.10	0.12	0.14	0.16	0.17	0.19	0.21
20	0.19	0.22	0.25	0.28	0.31	0.34	0.37
25	0.29	0.34	0.39	0.44	0.49	0.53	0.58
30	0.42	0.50	0.57	0.64	0.70	0.77	0.83
35	0.57	0.68	0.78	0.87	0.96	1.05	1.14
40	0.75	0.89	1.02	1.14	1.26	1.38	1.49
45	0.95	1.13	1.29	1.45	1.60	1.75	1.89
50	1.18	1.39	1.60	1.79	1.98	2.16	2.34
55	1.43	1.69	1.93	2.17	2.40	2.62	2.83
60	1.70	2.01	2.31	2.59	2.86	3.12	3.38
			WHITE ASH				
15	0.08	0.10	0.11	0.13	0.14	0.16	0.17
20	0.15	0.18	0.21	0.24	0.27	0.30	0.33
25	0.25	0.30	0.35	0.40	0.44	0.49	0.54
30	0.37	0.45	0.52	0.59	0.67	0.73	0.80
35	0.52	0.63	0.74	0.84	0.94	1.03	1.13
40	0.70	0.85	0.99	1.13	1.26	1.39	1.52
45	0.91	1.10	1.28	1.46	1.63	1.81	1.97
50	1.15	1.39	1.62	1.85	2.06	2.28	2.49
55	1.42	1.72	2.00	2.28	2.55	2.82	3.08
60	1.73	2.08	2.43	2.76	3.09	3.42	3.73
			YELLOW POPLAR				
15	0.05	0.08	0.11	0.15	0.19	0.23	0.28
20	0.09	0.14	0.19	0.25	0.31	0.39	0.47
25	0.14	0.20	0.28	0.37	0.47	0.58	0.70
30	0.19	0.28	0.39	0.52	0.66	0.81	0.98
35	0.25	0.37	0.52	0.68	0.87	1.07	1.29
40	0.32	0.48	0.66	0.87	1.11	1.36	1.65
45	0.40	0.59	0.82	1.08	1.37	1.69	2.04
50	0.48	0.72	0.99	1.31	1.66	2.05	2.47
55	0.57	0.85	1.18	1.55	1.97	2.43	2.94
60	0.67	1.00	1.38	1.82	2.31	2.85	3.44

Table 16.— *Tree volume to 10-centimeter top*
(In kilograms)

D.b.h. class (cm)	Total tree height (meters)						
	12	15	18	21	24	27	30
BLACK OAK							
15	0.06	0.08	0.09	0.11	0.12	0.14	0.15
20	0.12	0.15	0.18	0.21	0.24	0.27	0.30
25	0.21	0.26	0.30	0.35	0.40	0.45	0.50
30	0.31	0.39	0.46	0.53	0.61	0.68	0.75
35	0.44	0.55	0.65	0.76	0.86	0.96	1.07
40	0.60	0.74	0.89	1.03	1.17	1.31	1.44
45	0.79	0.97	1.16	1.34	1.53	1.71	1.89
50	1.00	1.24	1.47	1.71	1.94	2.17	2.40
55	1.24	1.54	1.83	2.12	2.41	2.70	2.98
60	1.52	1.88	2.23	2.59	2.94	3.29	3.64
RED OAK							
15	0.06	0.08	0.09	0.10	0.12	0.13	0.14
20	0.13	0.15	0.18	0.20	0.23	0.25	0.28
25	0.21	0.26	0.30	0.35	0.39	0.43	0.47
30	0.33	0.40	0.46	0.53	0.59	0.66	0.72
35	0.47	0.57	0.67	0.76	0.85	0.94	1.03
40	0.65	0.78	0.91	1.04	1.17	1.29	1.41
45	0.85	1.03	1.20	1.37	1.54	1.70	1.86
50	1.09	1.32	1.54	1.76	1.97	2.18	2.39
55	1.36	1.65	1.93	2.20	2.47	2.73	2.98
60	1.67	2.02	2.37	2.70	3.03	3.35	3.66
WHITE OAK							
15	0.10	0.10	0.11	0.11	0.12	0.12	0.12
20	0.19	0.20	0.21	0.22	0.23	0.24	0.24
25	0.32	0.34	0.36	0.37	0.39	0.40	0.41
30	0.50	0.53	0.55	0.58	0.60	0.61	0.63
35	0.72	0.76	0.80	0.83	0.86	0.88	0.91
40	0.98	1.04	1.09	1.14	1.17	1.21	1.24
45	1.30	1.37	1.44	1.50	1.55	1.60	1.64
50	1.66	1.76	1.85	1.92	1.99	2.05	2.11
55	2.08	2.21	2.31	2.41	2.49	2.57	2.64
60	2.56	2.71	2.84	2.95	3.06	3.15	3.24
HICKORY							
15	0.09	0.10	0.12	0.13	0.15	0.16	0.17
20	0.16	0.19	0.22	0.24	0.27	0.29	0.32
25	0.26	0.30	0.35	0.39	0.43	0.47	0.50
30	0.38	0.44	0.51	0.57	0.63	0.68	0.74
35	0.52	0.61	0.70	0.78	0.86	0.94	1.02
40	0.68	0.81	0.92	1.04	1.14	1.25	1.35
45	0.88	1.03	1.18	1.32	1.46	1.60	1.72
50	1.09	1.29	1.47	1.65	1.82	1.99	2.15
55	1.33	1.57	1.80	2.02	2.22	2.43	2.62
60	1.60	1.89	2.16	2.42	2.67	2.91	3.15
WHITE ASH							
15	0.07	0.08	0.10	0.12	0.14	0.15	0.17
20	0.13	0.16	0.19	0.22	0.26	0.29	0.32
25	0.20	0.26	0.31	0.36	0.42	0.47	0.52
30	0.30	0.38	0.46	0.54	0.62	0.70	0.78
35	0.43	0.54	0.65	0.76	0.87	0.98	1.09
40	0.57	0.72	0.86	1.01	1.16	1.31	1.46
45	0.74	0.92	1.11	1.31	1.50	1.69	1.88
50	0.93	1.16	1.40	1.64	1.88	2.12	2.37
55	1.14	1.43	1.73	2.02	2.32	2.61	2.91
60	1.38	1.73	2.09	2.44	2.80	3.16	3.52
YELLOW POPLAR							
15	0.05	0.08	0.11	0.15	0.19	0.24	0.30
20	0.08	0.12	0.18	0.24	0.31	0.40	0.49
25	0.12	0.18	0.26	0.35	0.46	0.58	0.72
30	0.16	0.25	0.36	0.48	0.63	0.79	0.98
35	0.21	0.32	0.46	0.63	0.82	1.03	1.27
40	0.26	0.41	0.58	0.79	1.03	1.29	1.59
45	0.32	0.50	0.71	0.96	1.25	1.58	1.95
50	0.38	0.59	0.85	1.15	1.50	1.89	2.33
55	0.45	0.70	1.00	1.36	1.77	2.23	2.74
60	0.52	0.81	1.16	1.57	2.05	2.58	3.18

Table 17. *Equation coefficients*[1]—$W = aD^bH^c$

Table reference	Species	a	b	c
3	Black oak	0.20110	2.16790	0.90260
	Red oak	0.05700	2.30890	1.10200
	White oak	1.09890	2.22180	0.48180
	Hickory	0.81630	1.85320	0.80010
	White ash	0.77560	2.24202	0.50569
	Yellow poplar	0.11415	1.80992	1.18635
4	Black oak	0.09530	2.23760	1.99950
	Red oak	0.11210	2.29900	0.92350
	White oak	3.25212	2.48148	0.01744
	Hickory	0.55940	2.01840	0.73760
	White ash	0.02277	1.92041	1.45806
	Yellow poplar	0.00738	1.84840	1.73228
5	Black oak	0.09050	2.30940	0.94550
	Red oak	0.11100	2.36560	0.86250
	White oak	1.72720	2.39810	0.20060
	Hickory	0.41710	2.09740	0.73040
	White ash	0.08193	2.21408	0.97872
	Yellow poplar	0.00408	1.72233	1.93225
6	Black oak	0.04782	2.23369	1.00040
	Red oak	0.05629	2.29601	0.92143
	White oak	2.00678	2.47164	0.00113
	Hickory	0.29717	2.01833	0.74444
	White ash	0.10491	2.23978	0.80092
	Yellow poplar	0.00392	1.84763	1.72350
7	Black oak	0.04553	2.30400	0.94700
	Red oak	0.05584	2.36140	0.86098
	White oak	0.84076	2.35819	0.25532
	Hickory	0.22462	2.09270	0.73845
	White ash	0.04527	2.19763	0.99926
	Yellow poplar	0.00196	1.71852	1.94168
8	Black oak	0.00126	2.21421	1.00357
	Red oak	0.00153	2.28573	0.91464
	White oak	0.04080	2.39233	0.08289
	Hickory	0.00653	2.01978	0.74640
	White ash	0.00250	2.21651	0.84179
	Yellow poplar	0.00011	1.81799	1.78323
9	Black oak	0.00119	2.27814	0.95563
	Red oak	0.00152	2.34839	0.85527
	White oak	0.02036	2.35739	0.25671
	Hickory	0.00502	2.09134	0.73907
	White ash	0.00115	2.17690	1.02488
	Yellow poplar	0.00006	1.70452	1.97632
10	Black oak	0.03533	2.16790	0.90260
	Red oak	0.01113	2.30890	1.10200
	White oak	0.11137	2.22180	0.48180
	Hickory	0.17026	1.85320	0.80010
	White ash	0.07936	2.24202	0.50569
	Yellow poplar	0.03923	1.80992	1.18635
11	Black oak	0.01761	2.23760	0.99950
	Red oak	0.01787	2.29900	0.92350
	White oak	0.14902	2.48148	0.01744
	Hickory	0.09287	2.01840	0.73760
	White ash	0.00975	1.92041	1.45806
	Yellow poplar	0.00468	1.84840	1.73228
12	Black oak	0.01466	2.30940	0.94550
	Red oak	0.01547	2.36560	0.86250
	White oak	0.10634	2.39810	0.20060
	Hickory	0.06378	2.09740	0.73040
	White ash	0.01509	2.21408	0.97872
	Yellow poplar	0.00369	1.72233	1.93225
13	Black oak	0.00888	2.23369	1.00040
	Red oak	0.00898	2.29601	0.92143
	White oak	0.09102	2.47164	0.00113
	Hickory	0.04974	2.01833	0.74444
	White ash	0.01528	2.23978	0.80092
	Yellow poplar	0.00246	1.84763	1.72350
14	Black oak	0.00743	2.30400	0.94700
	Red oak	0.00780	2.36140	0.86098
	White oak	0.05733	2.35819	0.25532
	Hickory	0.03483	2.09270	0.73845
	White ash	0.00868	2.19763	0.99926
	Yellow poplar	0.00180	1.71852	1.94168
15	Black oak	.000015	2.21421	1.00357
	Red oak	.000015	2.28573	0.91464
	White oak	.000137	2.39233	0.08289
	Hickory	.000068	2.01978	0.74640
	White ash	.000024	2.21651	0.84179
	Yellow poplar	.000005	1.81799	1.78323
16	Black oak	.000013	2.27814	0.95563
	Red oak	.000013	2.34839	0.85527
	White oak	.000087	2.35739	0.25671
	Hickory	.000049	2.09134	0.73907
	White ash	.000015	2.17690	1.02488
	Yellow poplar	.000004	1.70452	1.97632

Metrics of equation variables coincide with metrics of designated tables.

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1980. Weight and volume equations and tables for six upland hardwoods in southern Illinois. U.S. Department of Agriculture Forest Service, General Technical Report NC-60, 17 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

This paper presents tables of total tree green weight, green weight to a 5 cm and a 10 cm top diameter, dry weight to both 5 cm and 10 cm top diameter, and green volume to a 5 cm and a 10 cm top diameter for six upland hardwood species. Both metric and English unit tables are included.

KEY WORDS: Biomass, total tree utilization, yield tables.

Myers, Charles, David J. Polak, Donald Raisanen, Richard C. Schlesinger, and Les Stortz.

1980. Weight and volume equations and tables for six upland hardwoods in southern Illinois. U.S. Department of Agriculture Forest Service, General Technical Report NC-60, 17 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

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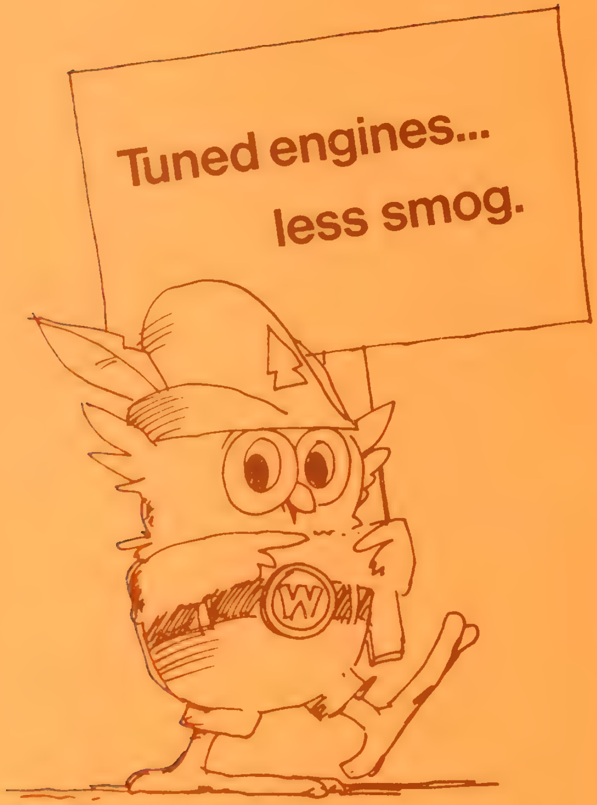
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less smog.

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Estimating plant biomass for undergrowth species of northeastern Minnesota

Lewis F. Ohmann, David F. Grigal, and Lynn L. Rogers

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ESTIMATING PLANT BIOMASS FOR UNDERGROWTH SPECIES OF NORTHEASTERN MINNESOTA FOREST COMMUNITIES

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North Central Forest Experiment Station,
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and **Lynn L. Rogers,** *Wildlife Biologist,*
North Central Forest Experiment Station, St. Paul, Minnesota

Knowledge of the plant biomass comprising a forest community is important to many aspects of multiple-use management. Direct measurement of biomass, however, is expensive and time-consuming to undertake each time biomass information would be useful. Fortunately, other measurements that can be made in the field less expensively or more easily can be used for estimating biomass.

Biomass prediction equations based on stem diameters have been available for several decades for the more important tree species. Similar equations for biomass of shrubs and their components have been developed more recently (Ohmann *et al.* 1976, Brown 1976, and others). With increased application (for example, estimating browse availability for hares (Grigal and Moody 1980)), these equations are being refined and extended and will become more useful for multiple-use management decisions, such as determining the carrying capacity for wildlife of a habitat in terms of woody browse. Determination of wildlife carrying capacity could be more meaningful if, along with better knowledge of food preferences, equations to predict biomass of ground cover plants could be developed.

Presented here are biomass prediction curves and equations, based on percent ground cover for 31 undergrowth plants typical of upland forest communities of northeastern Minnesota. Perhaps their publication will stimulate further development and/or refinement to improve their performance and to extend their application to a broader area and a greater variety of vegetative types (Payne 1974).

METHODS

Percent cover was estimated visually for each undergrowth species present in 1,060 1- by 2-ft (1,800cm/^{2}) plots, 660 located in aspen (*Populus tremuloides* Michx.) and 400 in red pine (*Pinus resinosa* Ait.) stands. The stands ranged from recently clearcut to more than 80 years old. Stands were 20 acres (8 ha) or larger with plots distributed systematically at 60-ft (20-m) intervals along transects that crossed topographic contours or recognizable banding in soils or vegetation. All plots were at least 20 paces (20 m) from stand edges, and no more than 20 plots were sampled in each stand.

At each plot, we estimated percent cover and clipped and separately bagged all plants of each undergrowth species present. Portions of plants that extended outside plots were discarded. The bagged plants were oven-dried at 68C for 48 hours and weighed.

The relation between percent cover and biomass was first explored with scatter diagrams. Results for a large number of species showed that a log-log plot of cover and biomass data was linear. This linearity can be expressed by the allometric relation

$$Y = aX^b \qquad (1)$$

where Y is plant biomass in grams dry weight and X is ground cover in percent. We used an iterative nonlinear approach to determine the appropriate parameters for each species. Where sufficient observations were available (arbitrarily set at 15 plots) the data were treated by species. Where fewer plots were available for a single species, species were grouped by genus or treated as miscellaneous fern, herb, and shrub groups.

The solutions for each species (or group) are the a and b parameters and their approximate 95 percent confidence intervals. The program also calculates a joint confidence interval for the function (in the sense that the confidence regions for a and b vary jointly.)

These confidence intervals are not uniform in the nonlinear case and cannot be easily described by a single algorithm. Thus, we present the results graphically to allow users to more easily approximate the confidence interval along various parts of the regression line.

Equations were developed separately for data collected in the aspen and red pine stands, but because confidence intervals overlapped, the data were combined and the parameters redetermined using the entire data set. Biomass values resulting from use of the prediction equations are for a 2-ft^2 (1,800-cm^2) area. These area values can be expanded to provide estimates on a per-acre (ha) basis.

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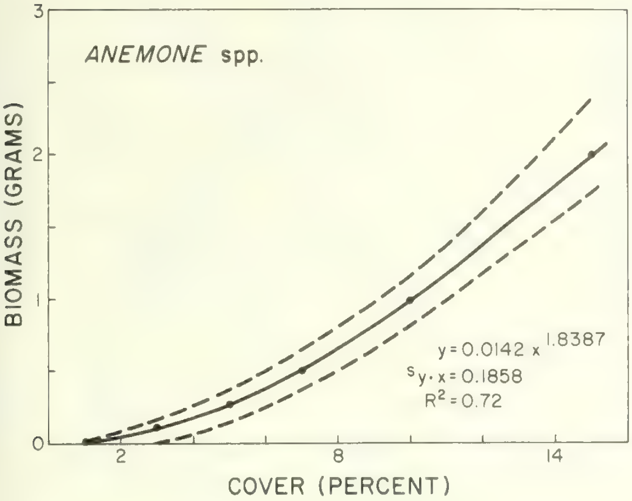
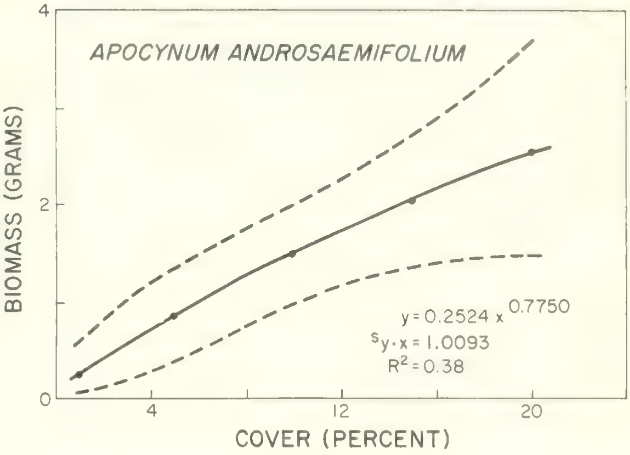
Grigal, D. F., and N. R. Moody. 1980. Estimation of browse by size classes for snowshoe hare. Journal of Wildlife Management 44(1):34-40.

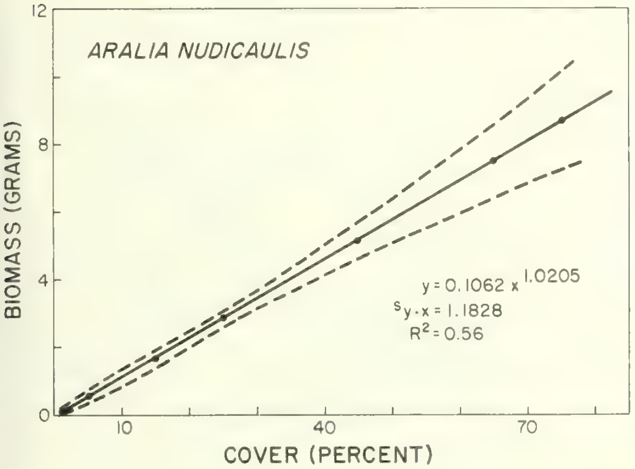
Ohmann, Lewis F., David F. Grigal, and Robert B. Brander. 1976. Biomass estimation for five shrubs from northeastern Minnesota. U.S. Department of Agriculture Forest Service, Research Paper NC-133, 11 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

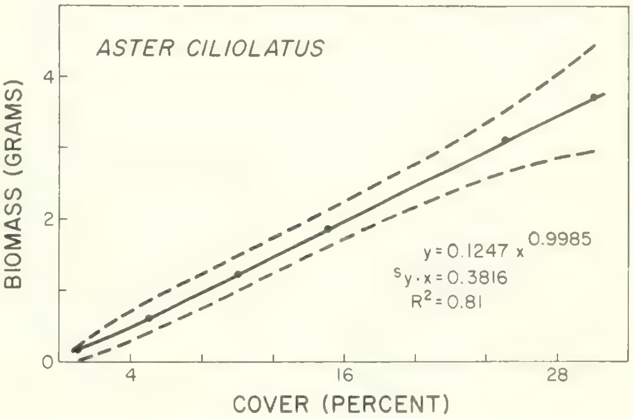
Payne, Gene F. 1974. Cover-weight relationships. Journal of Range Management 27(5):403-404.

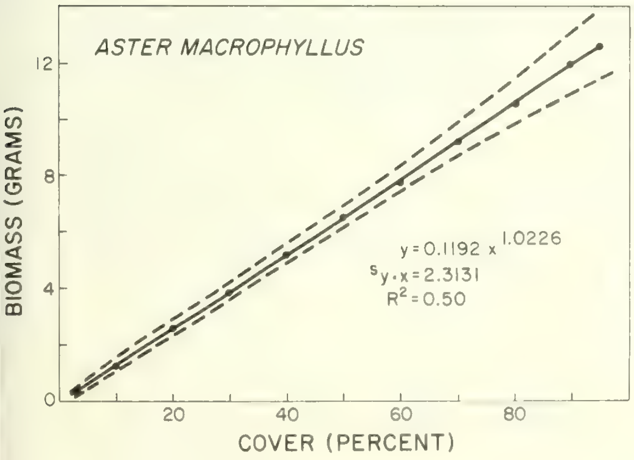
Nonlinear regressions (allometric relation $Y = aX^b$) of biomass (in grams) on cover (in percent), the 95 percent confidence interval about the regressions, the equation parameters, standard errors of the estimates, and R^2 values for a number of species or species groups from forest communities in northeastern Minnesota. Equation prediction values are for a 1- by 2-ft (1,800-cm^2) area.

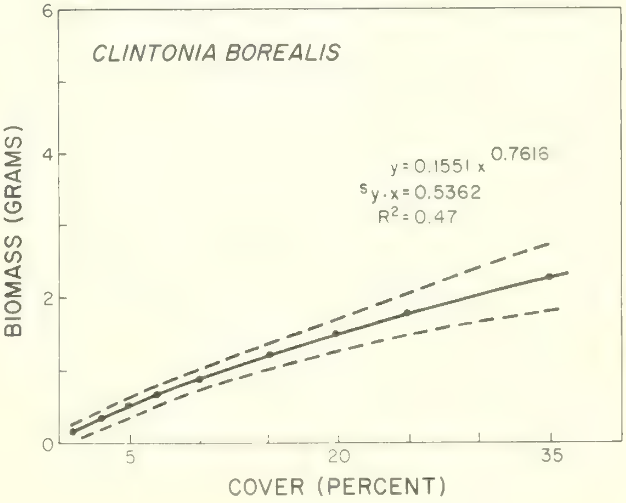


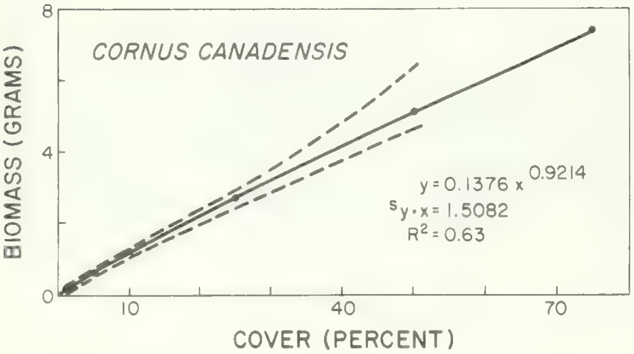


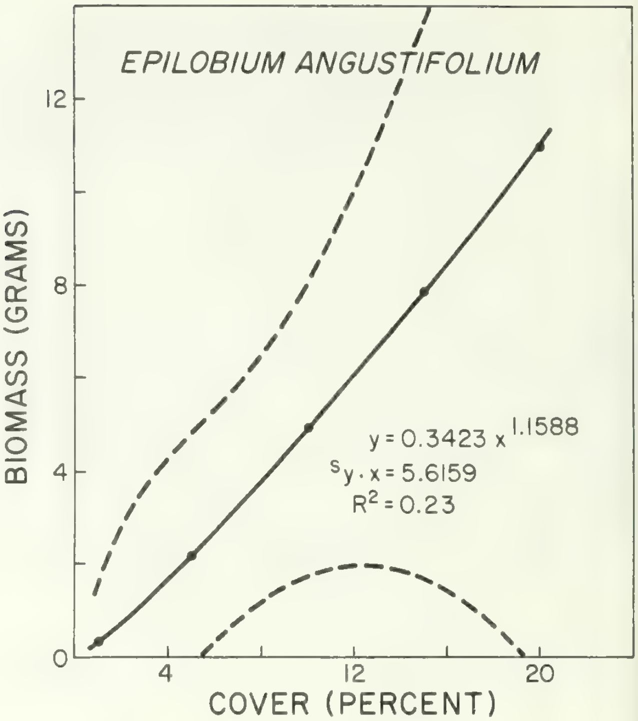


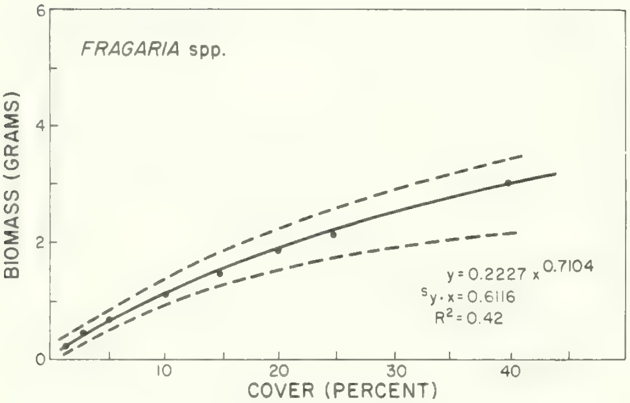


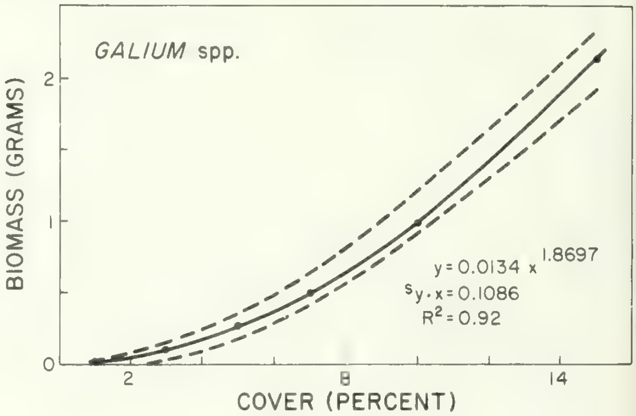


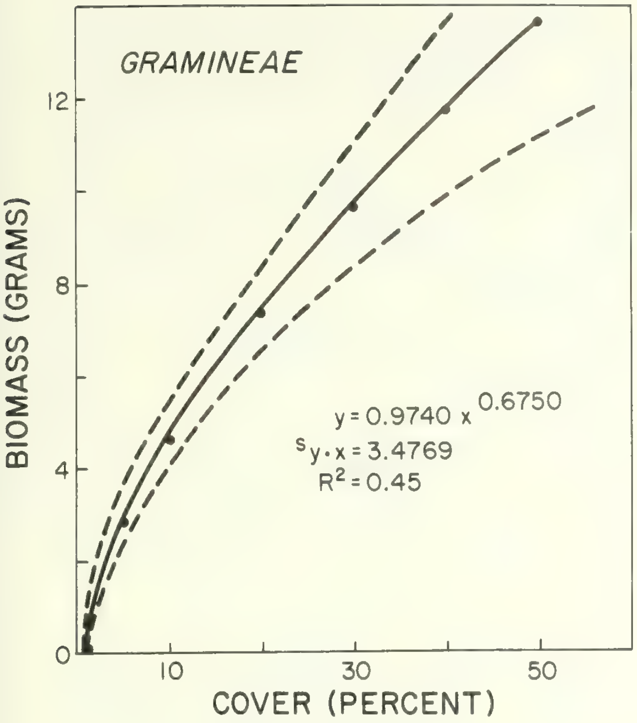


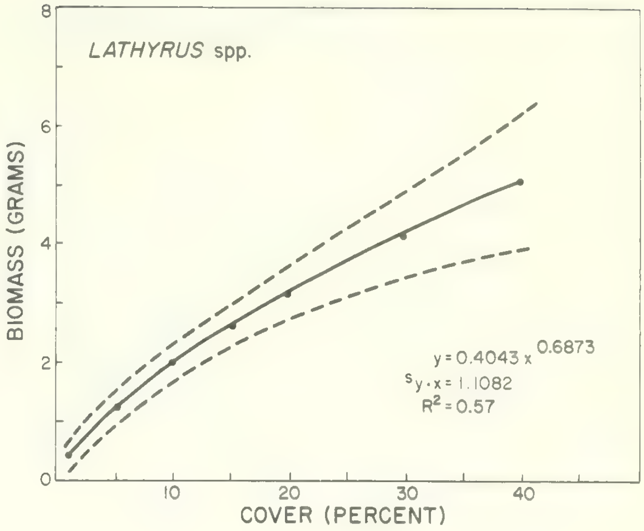

CORNUS CANADENSIS
y = 0.1376 x 0.9214
sy·x = 1.5082
R² = 0.63
BIOMASS (GRAMS)
0
4
8
10
40
70
COVER (PERCENT)

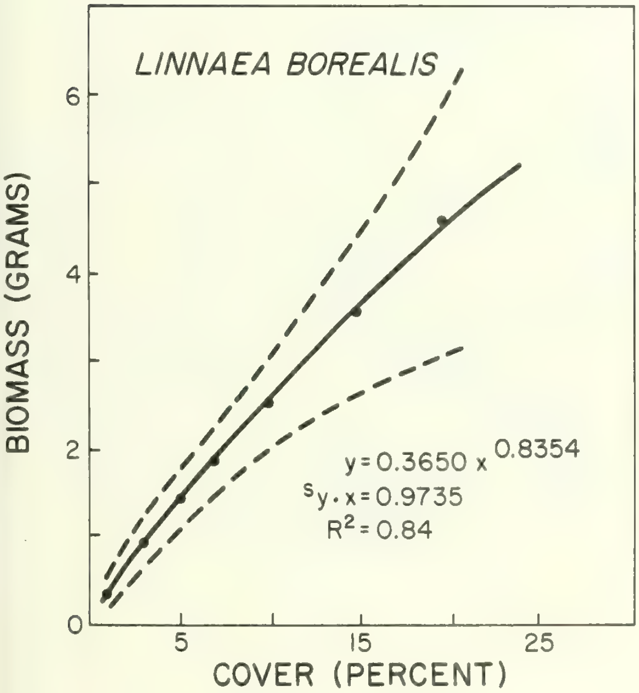

EPILOBIUM ANGUSTIFOLIUM
y = 0.3423 x 1.1588
sy·x = 5.6159
R² = 0.23
BIOMASS (GRAMS)
0
4
8
12
4
12
20
COVER (PERCENT)

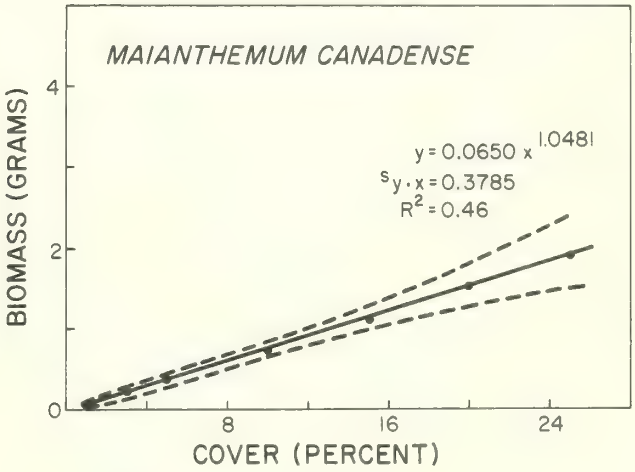

FRAGARIA spp.
y = 0.2227 x 0.7104
sy·x = 0.6116
R² = 0.42
BIOMASS (GRAMS)
0
2
4
6
10
20
30
40
COVER (PERCENT)

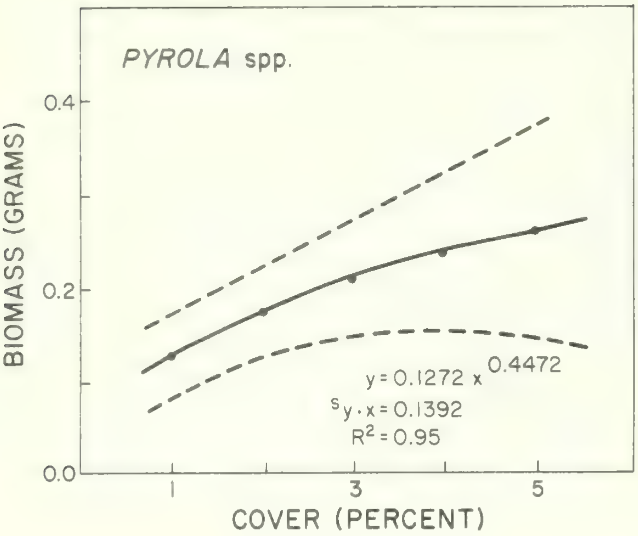

GALIUM spp.
y = 0.0134 x 1.8697
sy·x = 0.1086
R² = 0.92
BIOMASS (GRAMS)
0
1
2
2
8
14
COVER (PERCENT)

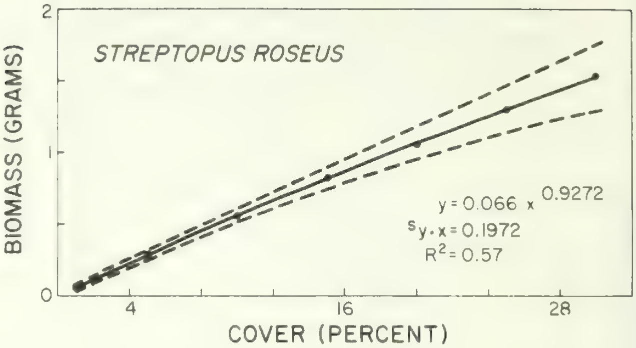

GRAMINEAE
BIOMASS (GRAMS)
COVER (PERCENT)
0
4
8
12
10
30
50
y = 0.9740 x 0.6750
sy·x = 3.4769
R2 = 0.45

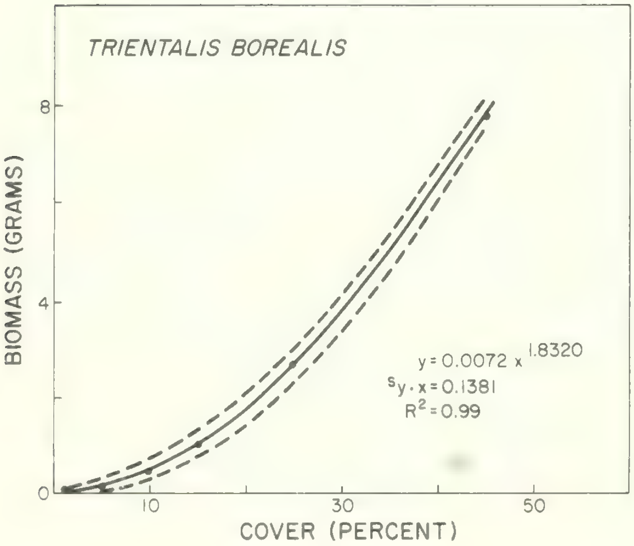

LATHYRUS spp.
BIOMASS (GRAMS)
COVER (PERCENT)
0
2
4
6
8
10
20
30
40
y = 0.4043 x 0.6873
sy·x = 1.1082
R2 = 0.57

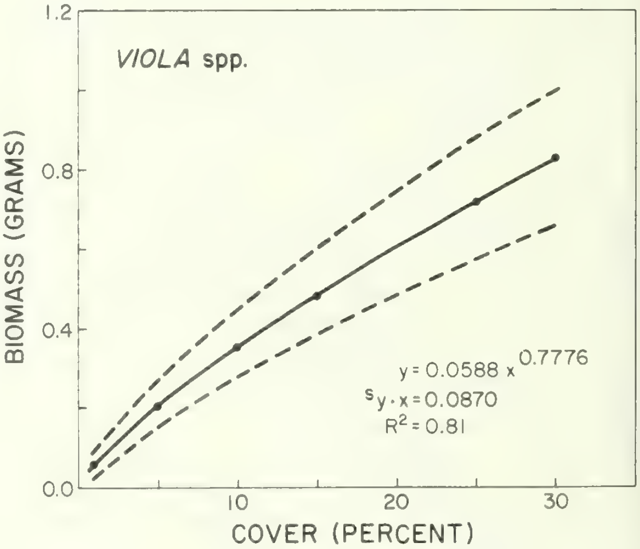

LINNAEA BOREALIS
BIOMASS (GRAMS)
COVER (PERCENT)
0
2
4
6
5
15
25
y = 0.3650 x 0.8354
sy·x = 0.9735
R2 = 0.84

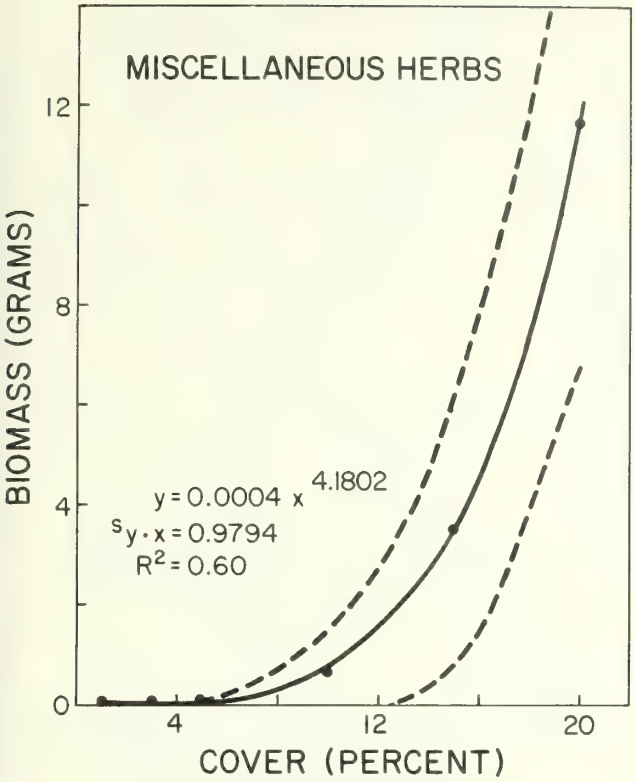

MAIANTHEMUM CANADENSE
BIOMASS (GRAMS)
COVER (PERCENT)
0
2
4
8
16
24
y = 0.0650 x 1.0481
sy·x = 0.3785
R2 = 0.46

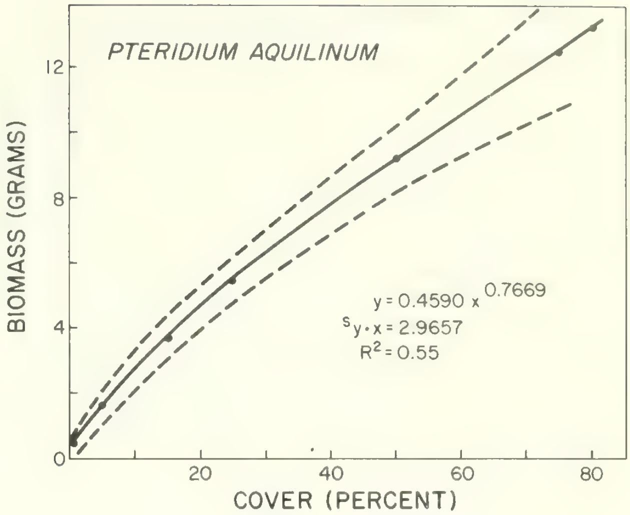

PYROLA spp.
BIOMASS (GRAMS)
0.4
0.2
0.0
1
3
5
COVER (PERCENT)
$y = 0.1272\ x^{0.4472}$
$s_{y \cdot x} = 0.1392$
$R^2 = 0.95$

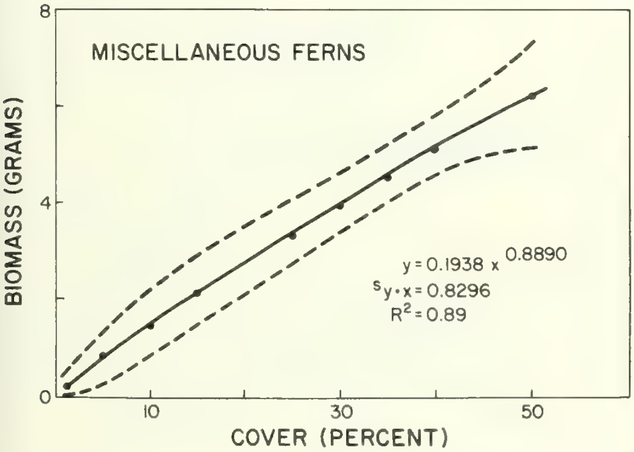

STREPTOPUS ROSEUS
BIOMASS (GRAMS)
2
1
0
4
16
28
COVER (PERCENT)
$y = 0.066\ x^{0.9272}$
$s_{y \cdot x} = 0.1972$
$R^2 = 0.57$

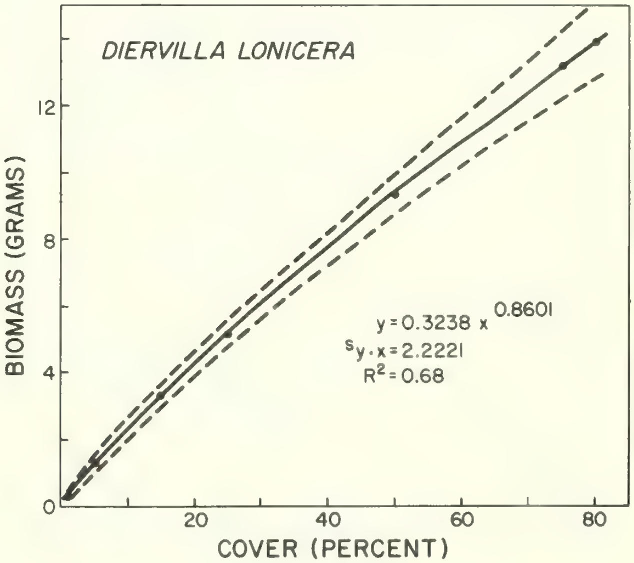

TRIENTALIS BOREALIS
BIOMASS (GRAMS)
8
4
0
10
30
50
COVER (PERCENT)
$y = 0.0072\ x^{1.8320}$
$s_{y \cdot x} = 0.1381$
$R^2 = 0.99$

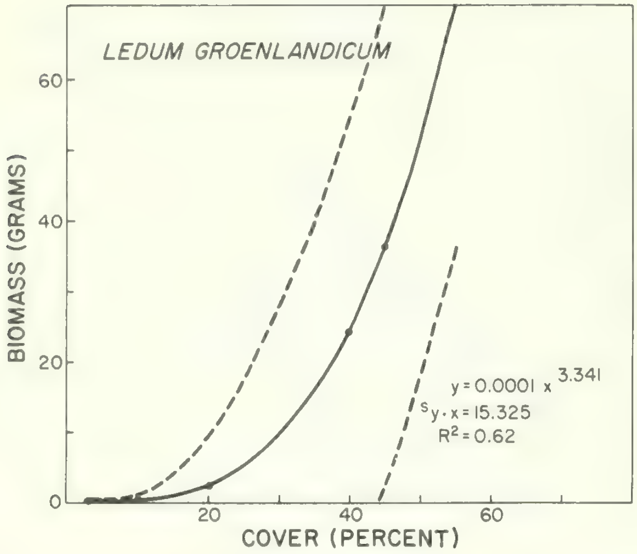

VIOLA spp.
BIOMASS (GRAMS)
1.2
0.8
0.4
0.0
10
20
30
COVER (PERCENT)
$y = 0.0588\ x^{0.7776}$
$s_{y \cdot x} = 0.0870$
$R^2 = 0.81$


MISCELLANEOUS HERBS
$y = 0.0004\ x^{4.1802}$
$s_{y \cdot x} = 0.9794$
$R^2 = 0.60$
BIOMASS (GRAMS)
0
4
8
12
COVER (PERCENT)
4
12
20

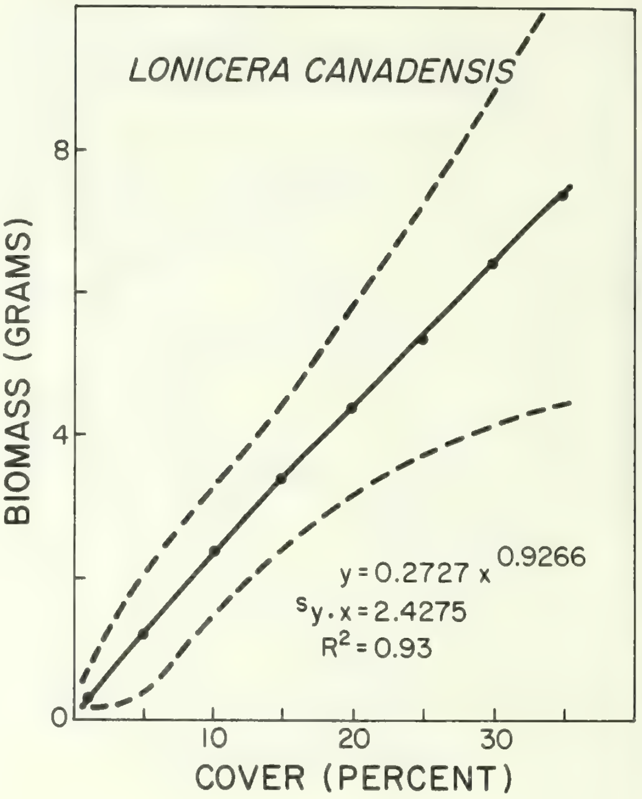

PTERIDIUM AQUILINUM
$y = 0.4590\ x^{0.7669}$
$s_{y \cdot x} = 2.9657$
$R^2 = 0.55$
BIOMASS (GRAMS)
0
4
8
12
COVER (PERCENT)
20
40
60
80


MISCELLANEOUS FERNS
$y = 0.1938\ x^{0.8890}$
$s_{y \cdot x} = 0.8296$
$R^2 = 0.89$
BIOMASS (GRAMS)
0
4
8
COVER (PERCENT)
10
30
50

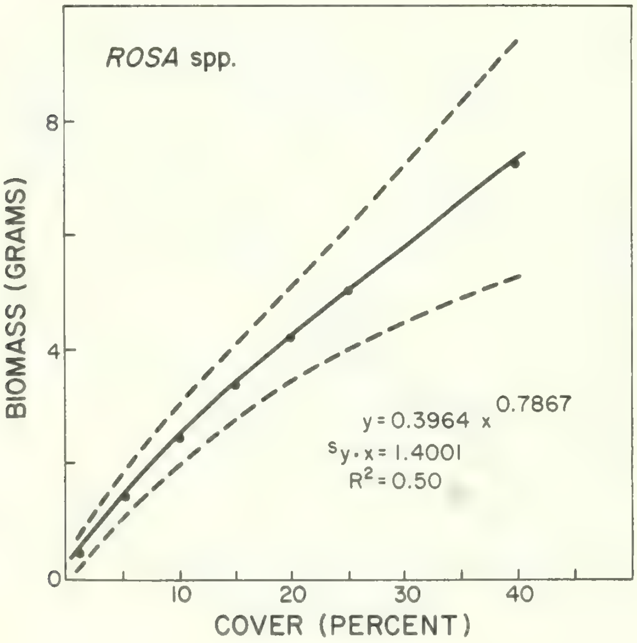

DIERVILLA LONICERA
$y = 0.3238\ x^{0.8601}$
$s_{y \cdot x} = 2.2221$
$R^2 = 0.68$
BIOMASS (GRAMS)
0
4
8
12
COVER (PERCENT)
20
40
60
80



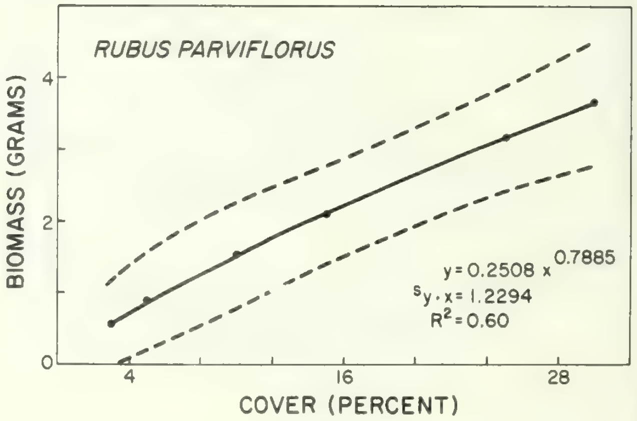
LEDUM GROENLANDICUM
BIOMASS (GRAMS)
0
20
40
60
COVER (PERCENT)
20
40
60
y = 0.0001 x^3.341
sy·x = 15.325
R² = 0.62



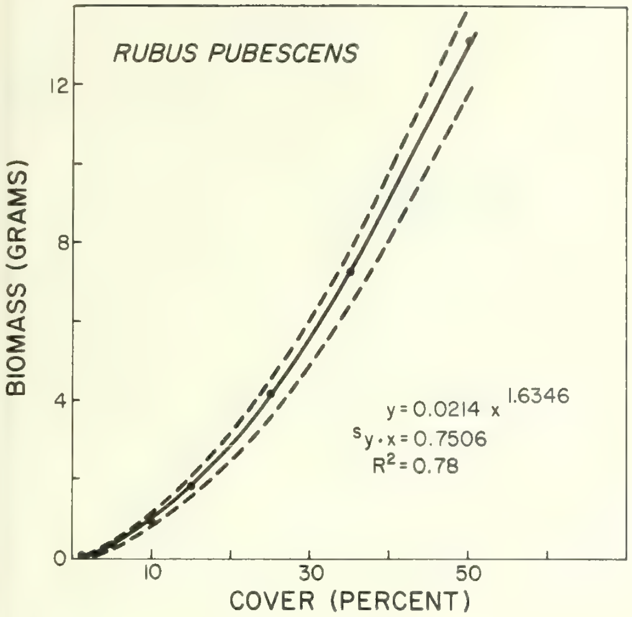
LONICERA CANADENSIS
BIOMASS (GRAMS)
0
4
8
COVER (PERCENT)
10
20
30
y = 0.2727 x^0.9266
sy·x = 2.4275
R² = 0.93

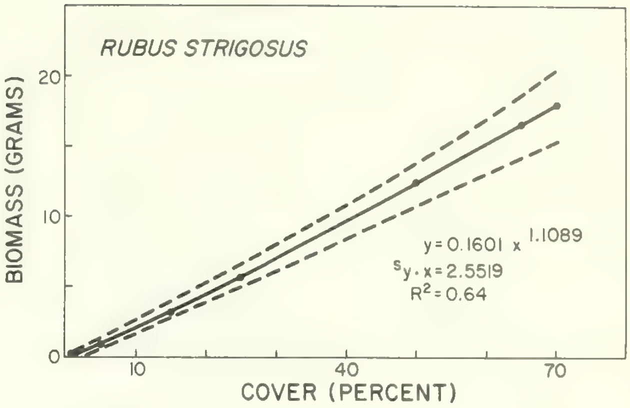


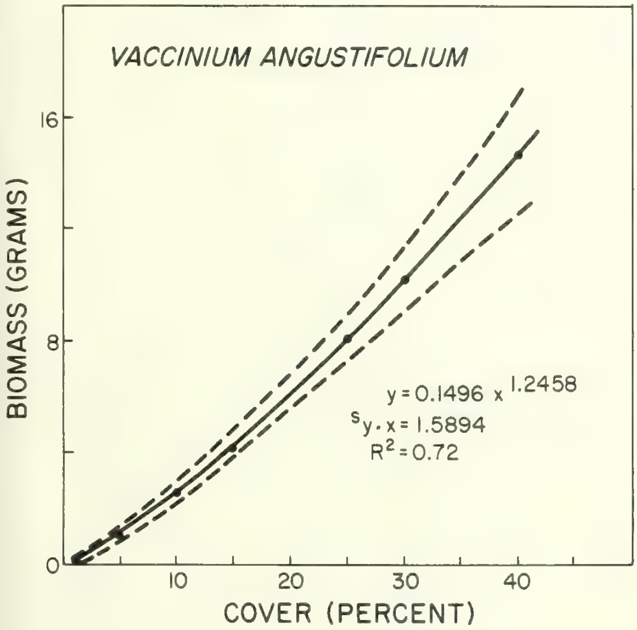
ROSA spp.
BIOMASS (GRAMS)
0
4
8
COVER (PERCENT)
10
20
30
40
y = 0.3964 x^0.7867
sy·x = 1.4001
R² = 0.50

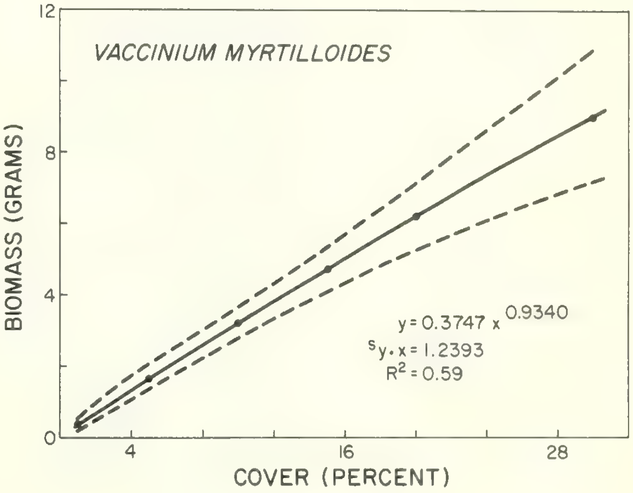


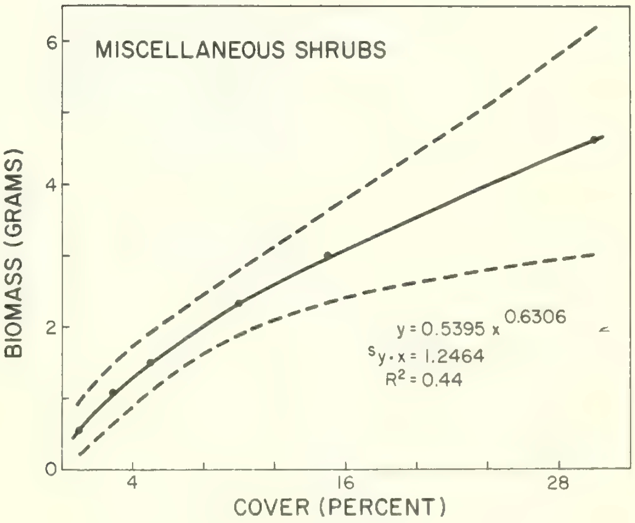
RUBUS PARVIFLORUS
BIOMASS (GRAMS)
0
2
4
COVER (PERCENT)
4
16
28
y = 0.2508 x^0.7885
sy·x = 1.2294
R² = 0.60


RUBUS PUBESCENS
BIOMASS (GRAMS)
COVER (PERCENT)
0
4
8
12
10
30
50
y = 0.0214 x 1.6346
sy·x = 0.7506
R2 = 0.78


RUBUS STRIGOSUS
BIOMASS (GRAMS)
COVER (PERCENT)
0
10
20
10
40
70
y = 0.1601 x 1.1089
sy·x = 2.5519
R2 = 0.64


VACCINIUM ANGUSTIFOLIUM
BIOMASS (GRAMS)
COVER (PERCENT)
0
8
16
10
20
30
40
y = 0.1496 x 1.2458
sy·x = 1.5894
R2 = 0.72


VACCINIUM MYRTILLOIDES
BIOMASS (GRAMS)
COVER (PERCENT)
0
4
8
12
4
16
28
y = 0.3747 x 0.9340
sy·x = 1.2393
R2 = 0.59


MISCELLANEOUS SHRUBS
BIOMASS (GRAMS)
COVER (PERCENT)
0
2
4
6
4
16
28
y = 0.5395 x 0.6306
sy·x = 1.2464
R2 = 0.44

MISCELLANEOUS HERBS[1]	**OBSERVATIONS** (number)
Achillea millefolium	1
Actaea rubra	2
Anaphalis margaritacea	1
Bidens connata	1
Carex spp.	4
Coptis groenlandica	13
Equisetum spp.	2
Goodyera repens	4
Halenia deflexa	1
Hapatica americana	2
Lactuca spp.	1
Melampyrum lineare	1
Mitella nuda	8
Petasites palmatus	10
Polygala paucifolia	2
Potentilla norvegica	1
Rumex spp.	2
Solidago spp.	6
Taraxacum officinale	1
Trillium spp.	3
Unidentified	4
Vicia americana	13
MISCELLANEOUS FERNS[1]	
Athyrium filix-femina	8
Cynoglossum boreale	1
Dryopteris phegopteris	1
Osmunda claytoniana	2
Unidentified	3
MISCELLANEOUS SHRUBS[2]	
Chimaphila umbellata	3
Comptonia peregrina	1
Cornus stolonifera	1
Corylus cornuta	1
Gaultheria procumbens	7
Lonicera dioica	5
Lonicera hirsuta	12
Ribes spp.	14

[1] See graph, page 7.

[2] See graph, page 9.

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1981. Estimating plant biomass for undergrowth species of northeastern Minnesota forest communities. U.S. Department of Agriculture Forest Service, General Technical Report NC-61, 10 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Biomass prediction equations were developed for some common ground cover plants from forest communities of northeastern Minnesota. The allometric function was used to predict biomass (dry weight) with ocular estimates of percent ground cover of the plant as the independent variable.

KEY WORDS: Wildlife habitat, nonlinear regression analysis, allometric relations, dry weight, plant ecology.

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Workshop on seedling physiology and growth problems in OAK PLANTING

Columbia, Missouri,
November 6-7, 1979

ABSTRACTS

North Central Forest Experiment Station
Forest Service, U.S. Department of Agriculture

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WORKSHOP ON SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTING, COLUMBIA, MISSOURI, NOVEMBER 6-7, 1979 (ABSTRACTS)

Compiled by Paul S. Johnson and H. E. Garrett

Sponsored by

School of Forestry, Fisheries, and Wildlife
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USDA, Forest Service
St. Paul, Minnesota

PREFACE

On November 6-7, 1979, a group of foresters, forest scientists, tree physiologists, and horticulturists met in Columbia, Missouri to discuss recent research results on seedling physiology and growth problems in oak planting. This workshop was prompted by the recent increase in interest among North American foresters in planting oak. The purpose of the workshop was thus to provide a forum for exchange of ideas and research results in three subject areas: (1) physiology and genetics, (2) seedling propagation and production methods, and (3) field performance of planted oaks. The workshop was jointly sponsored by the School of Forestry, Fisheries, and Wildlife, University of Missouri, Columbia, and the North Central Forest Experiment Station, USDA Forest Service. H. E. Garrett and Paul S. Johnson were co-chairmen. Abstracts of the papers given at the workshop are presented here.

Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

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PLANTING PROBLEMS IN SOUTHERN APPALACHIA

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Oak in southern Appalachia fail to regenerate naturally and to produce desirable species composition. Adequate stocking of northern red oak (*Quercus rubra* L.) is particularly hard to achieve. Foresters in the region note that they would plant oak if suitable techniques and material were available; at present little research is aimed at developing these.

The main planting problem is poor shoot growth of transplants under typical forest and old field conditions. Little attention has yet been given to planting advance regeneration, which avoids some problems inherent in this setting but introduces others. A wide array of planting techniques have been researched but none have solved the problems under operational conditions. Adequate growth can be obtained with combinations of intensive cultivation, nitrogen amendment, and large root stocks, but together these procedures are presently too expensive for forest culture.

Further progress in developing economical planting techniques will depend on a better understanding of the genetics and physiology of shoot elongation. Therefore, future research should be concentrated on those aspects of early root and shoot growth that have a direct relation to oaks' establishment phase. Further studies of nutrient relations and the genetics of early shoot growth should have especially high potential for improving oak performance.

OAK PHYSIOLOGY AND GENETICS

LEAF STRUCTURE OF SOUTHERN APPALACHIAN SPECIES

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and
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A linear displacement transducer was used to measure the leaf thickness of sun and shade leaves collected from eight oak species growing in the Mountain and Eastern Coalfield Region of Kentucky. Thickness of sun leaves varied from 155μ in *Quercus rubra* L. to 306μ in *Quercus stellata* Wang. Sun leaves were thicker than shade leaves for all species. Variation in thickness was greater among sun leaves. Sun leaves for the more shade-tolerant species were similar in morphology to shade leaves of the more shade-intolerant species.

WATER RELATIONS OF WHITE OAK

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and
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Analysis of white oak (*Quercus alba* L.) physiology during the past 8 years has shown that the degree of water deficit in a specific individual is a complex function of site microclimate, and drought-resistance characteristics. Water stress in white oak seedlings was often greater than in mature trees apparently because a large root system helps to avoid drought. Additional drought resistance characteristics included a leaf water potential for stomatal closure of -26.1 bars and the ability to maintain positive net photosynthesis at a leaf water potential of -29.7 bars.

A model was proposed that described the physiological and phenological functions of mature trees and seedlings. This model proved particularly useful in examining the patterns of growth periodicity. Seedlings exhibited the following general characteristics: (a) a short and simple transport pathway for water and photosynthate, (b) small carbohydrate reserves, which makes them dependent on current photosynthate for growth, (c) no root growth when the shoot was dormant, (d) distinct alternating periods of root and shoot growth, and (e) multiple shoot flushes. In contrast, mature trees had (a) a complex and lengthy transport pathway, (b) large carbohydrate reserves, (c) nearly continuous root growth, which was limited by environment (primarily temperature and moisture) rather than by the amount of carbohydrate available for growth, (d) some root growth reduction during leaf expansion, (e) only one flushing period per season, and (f) peaks in root growth in early spring before budburst, late spring after full leaf expansion, and early fall before leaf senescence.

HORMONAL CONTROL OF ROOT REGENERATION

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Early, vigorous root regeneration of planted tree seedlings is a critical factor in establishment and early growth of hardwood plantations. New lateral roots on taproots are initiated internally on the pericycle, or in older roots, on the cork cambium. The root initiation process appears to be triggered by a several-fold increase in root auxin concentrations that lasts about 24 hours.

Root regeneration (RR) of spring-lifted red oak (*Quercus rubra* L.) stock varies greatly from year to year for largely unknown reasons. Generally, RR of fall-lifted stock is much poorer than spring-lifted stock. Root regeneration was not related to root carbohydrate levels.

Red oak, white ash (*Fraxinus americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.) 1-0 nursery stock were root soaked in various hormone solutions (IAA, Kinetin, GA_3) for 20 hours and then grown for 4 weeks in a greenhouse. IAA at 100 to 200 mg/l significantly increased RR. Kinetin alone either had no effect or was inhibitory to seedling growth. GA_3 at 500 mg/l reduced RR of red oak, stimulated RR of white ash, and inhibited leaf development of yellow-poplar. Among red oaks planted in the field, growth was best for trees pretreated with 100 mg/l IAA plus 0.1 mg/l Kinetin. The use of hormones to enhance early growth of planted trees warrants further research.

INDOBUTYRIC ACID ENHANCES ROOT REGENERATION IN TRANSPLANTS

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Root regeneration of transplanted pin oak (*Quercus palustris* Muenchh.), scarlet oak (*Q. coccinea* Muench.), and white oak (*Q. alba* L.) was shown to be closely correlated with bud and shoot growth. Indobutyric acid-potassium salt (IBA) treatment to the roots accelerated root regeneration over that of untreated plants. Optimum preplant IBA treatment was a 5-minute aqueous root soak of 1,000 mg/liter.

New root regeneration was also stimulated by localized applications of IBA. New roots developed not only at the base of the tap root but also at the site of IBA application. Successful localized treatment was achieved with IBA impregnated toothpicks inserted through the roots or IBA impregnated string wrapped around the roots midway to the crown.

Napthalene acetic acid - K salt (1,000 mg/liter) was almost as effective as IBA in stimulating new root initiation but inhibited elongation and branching of these new roots. 2,4-D, 2,4,5-T and several other auxins did not stimulate root regeneration.

The use of IBA to treat roots of oak transplants may have application in improving survival and subsequent growth of new oak plantings.

OAK PHYSIOLOGY AND GENETICS

PATTERNS OF GEOGRAPHIC VARIATION IN NORTHERN RED OAK

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The flushing date of northern red oak (*Quercus rubra* L.) displays a geographic pattern. In the north-central region, the earliest-flushing trees are those of northwestern origin. The flushing trend is then "eastward" from trees of northern origin to trees of northeastern origin and "southward" to trees of central and southern provenance. The latest-flushing trees are those of mid-latitude origins from southern Michigan to Pennsylvania. The time of autumn leaf coloration is strongly correlated with seed source latitude. Early coloration is associated with high latitude and late coloration with low latitude. The capacity to survive summer heat and drought conditions also varies geographically. Trees native to regions that have hot, dry summers, e.g. Kansas, are most capable of survival. Growth rate varies with geographic region of origin, but the regional effect is small except for the slow growth of trees of extreme northern provenances planted in areas farther south. Growth rate also varies with stand or local population and with progeny and is apparently influenced most by these factors. The apparent importance of local variation in growth rate of red oak indicates that further improvement efforts in the north-central region should be concentrated on phenotypic selection without particular regard to geographic origin. For planting in the 38° to 43° latitudinal belt in the region, native trees for progeny testing may be selected anywhere west of the Appalachians, except in the extreme north as described and south of the southernmost of our provenances.

OAK PHYSIOLOGY AND GENETICS

GROWTH MODELS AND THE EXPERIMENTAL ANALYSIS OF GROWTH PATTERNS IN TREES

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Most oak species growing in the Central United States display a characteristic shoot growth pattern: periods of growth separated by periods of rest. Seedlings and saplings may have as many as four growth flushes in a single growing season but mature trees have only one, or rarely two. Neither the alternation between shoot growth and rest nor the difference between the shoot growth patterns of juvenile and adult trees are directly related to the environment. To understand such phenomena, we should know how growth and development of a tree's organs depend on plant-environment interactions as well as the "correlative", functional relation between organs and organ systems. Without adequate analysis and integration of these major aspects of tree function and development, we will never understand how a tree works. Integration of our fragmented and scarce knowledge requires the construction of explanatory, hierarchical models constituting collective hypotheses of the complex system "tree". Although such models will at first have only modest predictive power, they should assist us in recognizing important gaps in our knowledge and in devising experimental tests to fill these gaps. Work on rhythmic shoot growth and the determination of shoot growth patterns by correlative changes illustrates that testable hypotheses can arise from such growth models of trees.

OAK PHYSIOLOGY AND GENETICS

ROOT STARCH CONTENT INDICATES EFFECTS OF DEFOLIATION

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Starch content in roots of oak trees can be used as an indicator of the effects of defoliation on the tree. Studies utilizing both natural (insect) and artificial defoliation showed that starch content in the roots declined in proportion to the severity and number of consecutive defoliations. Starch content can be determined by the simple histochemical iodine test, and the effects of defoliation on an individual tree or a group of trees can be judged by the intensity of the stained starch. Tissue taken from the buttress roots just below the soil line indicated the status of starch in the root system. Starch content in the roots not only shows the effects of defoliation but may also indicate the probability of the tree's surviving an additional defoliation. Oaks that had low starch before defoliation or no starch after defoliation were more likely to die than trees with moderate or high starch levels before defoliation or low or moderate starch levels after defoliation. Even seasonal differences in the effects of defoliation were related to starch content: defoliation in months when starch content was low resulted in greater crown damage and mortality than defoliation in months when starch content was high. Starch reserves seem to be a critical factor in the survival of oaks after defoliation.

OAK SEEDLING PROPAGATION AND PRODUCTION METHODS

SEED TECHNOLOGY PROBLEMS

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Extensive research suggests three critical periods in the collection and care of *Quercus* acorns: (1) collection, (2) extended storage, and (3) delayed germination. Only mature acorns should be collected, and acorn color is the best and easiest index of maturity. Acorns of the red oak group can be stored up to 3 years by keeping acorn moisture content high, by maintaining the temperature slightly above freezing, and by allowing gas exchange between container and cooler atmosphere. Attempts to store acorns of the white oak group have failed completely. Control of germination could help in storage and in nursery operations, but research in this area is just beginning.

OAK SEEDLING PROPAGATION AND PRODUCTION METHODS

COLLECTING, STORING, AND GERMINATING ACORNS OF SOUTHWESTERN OAKS

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Acorn loss to insects, birds, rodents, and other wildlife prompted seed collection of four oak species 2 months or more prior to normal acorn drop. *Quercus kelloggii* Newb. acorns begin to fall by late September and *Q. chrysolepis* Liebm., *Q. wislizenii* A. DC., and *Q. dumosa* Nutt. acorns fall from mid-October through November.

Viable acorns were picked as early as August 24 for *Q. kelloggii, Q. chrysolepis, Q. dumosa,* and a few *Q. wislizenii* were picked as early as August 10. Cold stratification was not required; however, *Q. kelloggii* acorns picked on July 27 and *Q. chrysolepis* acorns picked August 10 germinated after storage at 3 C for 1 month. Germination tests showed that the tip of the acorn shell must be removed to obtain good germination of prematurely picked acorns.

Long-term storage of prematurely picked acorns was generally poor due to loss of viability and to germination during storage. *Q. dumosa* acorns picked in August and dried to 40 percent of their initial fresh weight remained viable. Because acorn moisture content drops as they mature, acorns can only be dried to 60 to 80 percent of their fresh weight at maturity. *Q. dumosa* acorns picked in early September and dried to 60 percent of their fresh weight did not germinate in storage and remained viable for 12 to 15 months.

OAK SEEDLING PROPAGATION AND PRODUCTION METHODS

GERMINATION AND OCCURRENCE OF NORTHERN RED OAK IN THE LAKE STATES

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Constant temperature tests showed that northern red oak (*Quercus rubra* L.) germinate best at 34°F. Direct seeding trials and soil surface temperature measurements supported the low temperature concept. The time period of favorable temperatures was longer on soil scarified sites than on unscarified sites but it was still not long enough for maximum germination.

These findings partially explain not only the sporadic chronological and geographical occurrence of red oak regeneration but also its greater frequency on north slopes and in uncut stands and also its association with sugar maple, (*Acer saccharum* Marsh.). Among the desirable hardwoods, sugar maple has the lowest germination temperature requirement. Temperature seemingly accounts for the abundance of sugar maple to a far greater extent than tolerance. Northern white-cedar (*Thuja occidentalis* L.) and hemlock (*Tsuga canadensis* (L.) Carr.) for example, have equal or greater tolerance but seldom regenerate. However, both require high germination temperatures, which rarely coincide with favorable moisture conditions.

The best chance of obtaining more red oak may be to sow pregerminated acorns at or prior to snow melt to assure the most favorable temperature-moisture conditions and to reduce their exposure time to predators.

OAK SEEDLING PROPAGATION AND PRODUCTION METHODS

MICROCULTURE OF *QUERCUS RUBRA:* POTENTIAL FOR MICROPROPAGATION OF OAK-WILT RESISTANT GENOTYPES

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Microculture (tissue culture) of woody plants is receiving increased attention by researchers. The emphasis of genetic improvement work through microculture has shifted from the research laboratory to practical application. Micropropagation is now being commercially utilized in the woody ornamental industry and the same techniques should be applicable for multiplying desirable genotypes of forest tree species. By utilizing simple media and laboratory procedures, *Betula* species can be rapidly multiplied in culture by use of shoot-tip cultures. Utilizing only 125 square feet of culture shelf space, ½ million birch can be clonally produced each year. The shoots produced in culture can be rooted within 2 weeks by conventional means and then can be treated as regular seedlings. The cultures show high genetic stability and the resultant plants are vigorous and highly uniform, which make them particularly useful for mass production, accelerated growth programs. When selections of *Quercus rubra* L. resistant to oak wilt, *Ceratocystis fagacearum,* were isolated, we conducted some preliminary work to see if the procedures used with birch would be applicable for multiplying oak. Rapidly multiplying shoot-tip cultures of *Quercus* have been produced. Interestingly, oak appears to retain its episodic growth pattern in culture. The use of micropropagation as a means of producing large numbers of desirable selections of dicot trees has been demonstrated; however, only a few species have been utilized. The successful application of these techniques for producing the difficult-to-propagate, episodically-growing species such as *Quercus* would be highly informative.

RAISING CONTAINER-GROWN BUR OAK SEEDLINGS IN GREENHOUSES

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A regime has been developed to grow 20-25 cm tall bur oak (*Quercus macrocarpa* Michx.) seedlings with 5-8 mm caliper in large containers for spring planting in the northern Great Plains. Limited experience indicates this regime is also suitable for northern red (*Quercus rubra* L.) and black oak (*Q. velutina* Lam.).

Plant germinating acorns in 300-500 ml containers 1 cm below the surface of 1:1 #1 sphagnum peat and vermiculite of 3-5 mm particle size, containing 3 percent forest duff to provide mycorrhizal fungi. If seeded March 15, the crop flushes three times and reaches 20-25 cm height by June 15. Move the seedlings to a shadehouse to complete their caliper and dry weight growth, and begin a second crop in the greenhouse. During germination, set furnace at 21 C day and night, begin full cooling at 27 C and maintain 70 ± 20 percent relative humidity. Keep rootball moist, allow surface to dry between waterings, and add no fertilizer until the first leaves are fully expanded.

During the multiple flushing stage set furnace at 24 C day and night, begin cooling at 32 C with full cooling at 37 C and maintain 70 ± 20 percent relative humidity. Add supplemental light at night and raise CO_2 level during the day. Do not shade. Keep rootball moist with high N nutrient solution, pH 6-7. Rinse foliage after watering. Spray as needed to control insects and foliage diseases. Bait the floor and entryways to control rodents.

Hardening will occur naturally in the shadehouse, and the seedlings need only be mulched to be overwintered. If the second crop is still too small by September 15, it must be hardened in the greenhouse. During hardening set furnace at 15 C day and night and begin cooling at 25 C. Turn off supplemental light and CO_2 generator. Water with low N, high PK nutrient solution. After 5 weeks reduce heat to 1 C, with maximum permissible day temperature 10 C. After 5 weeks at 1 C, seedlings can be moved to the shadehouse, mulched, and stored until spring.

POTENTIAL VALUE OF SPECIFIC ECTOMYCORRHIZA TO ARTIFICIAL REGENERATION

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Little is known of the significance of specific ectomycorrhizal fungi to growth and development of oak seedlings. Most work has been limited to field observations, field association of specific fungi, aseptic synthesis tests, use of oak soil as a source of inoculum, and inoculations with truffle fungi. Techniques have recently been developed to form specific ectomycorrhizae on pine seedlings in conventional tree nurseries. Field trials on adverse and routine sites show that pine seedlings benefit more from ectomycorrhizae formed by *Pisolithus tinctorius* than from naturally occurring ectomycorrhizae formed by *Thelephora terrestris* or other fungi. These results indicate that specific ectomycorrhizae formed in the nursery can be used to improve survival and growth of pine seedlings on various sites. Recently, the program was expanded to determine the significance of specific ectomycorrhizae in nursery production of oaks.

Techniques developed to infest fumigated nursery soil with *Pisolithus* ectomycorrhizae for pine seedlings worked well for white oak (*Quercus alba* L.) (fall sowing) and northern red oak (*Q. rubra* L.) (spring sowing). Genetic variation in white oak controlled the amount of ectomycorrhizae formed and the amount of stimulation derived by seedlings from *Pisolithus* ectomycorrhizae. Isolates of *P. tinctorius* from oak were not as effective as pine isolates in forming ectomycorrhizae and stimulating growth of red oak seedlings. These preliminary studies proved that techniques developed for inoculum production, soil infestation, and seedling root assessments of pine can be applied to oak seedlings. The next logical step is field testing.

NUTRIENT REGIME AND INOCULATION RATE INFLUENCE GROWTH OF CONTAINER-GROWN RED OAK SEEDLINGS

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and
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Stratified *Quercus rubra* L. seed were sown in polyethylene-coated paper bands (4 x 4 x 10 1/2") filled with medium-fine silica sand inoculated with *Pisolithus tinctorius* (0, 100, 200, or 300 ml equivalents/ft^2). Modified Hoaglands solutions were added weekly after shoot emergence to provide nitrogen (N) levels of 0, 100, and 200 ppm and phosphorus (P) levels of 0, 50, and 100 ppm. The experimental design was a 4 x 3 x 3 randomized block factorial with 4 replications of each treatment combination. Seedlings were grown for 17 weeks in a greenhouse with supplemental fluorescent and incandescent light to give a 16-hour photoperiod. Seedling height; number of leaves; stem diameter; percent *P. tinctorius* colonization; and dry weight of leaves, stems, and roots were determined. Percent colonization was erratic and was not correlated with the rate of inoculation.

Seedling height, stem diameter, dry weight of the various tissue components, and foliar nitrogen concentration were significantly increased by increasing the amounts of either nitrogen, phosphorus, or the level of inoculum. Dry weight of lateral roots and the number of leaves per seedling were not influenced by *P. tinctorius* application. All variables showed significant interaction between nitrogen and rate of inoculation. No significant phosphorus-inoculum interaction was detected. Increasing nitrogen concentrations in the fertilizer solution significantly reduced the P concentration in the foliage. Foliar N/P ratio increased with increasing N/P ratio in the nutrient solution and overall nutrient concentration. Inoculation rate had no significant effect on foliar N/P ratio.

The greatest growth response and stem diameter were achieved with 300 ml/ft^2 of *P. tinctorius* and nitrogen and phosphorus levels of 100 and 50 ppm, respectively.

Oak Seedling Propagation and Production Methods

EFFECTS OF VARIOUS STORAGE REGIMES AND PACKAGING METHODS ON ROOT REGENERATION AND HARDWOOD SEEDLING QUALITY

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The dependence of survival and early shoot growth of out-planted hardwood seedlings on root regeneration indicate the need to adapt nursery cultural practices and storage techniques to maximize physiological quality of planting stock. Recent experiments in Ontario on overwinter storage (November-April) of sugar maple (*Acer saccharum* Marsh.), silver maple (*Acer saccharinum* L.), red oak (*Quercus rubra* L.), white ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), paper birch (*Betula papyrifera* Marsh.), and black walnut (*Juglans nigra* L.) nursery stock indicate that storage temperature and packaging method markedly affect physiological quality and out-planting performance. Storage at -5 and -10 C resulted in low root regeneration and poor shoot growth compared to survival and growth of spring-lifted control stock. Root regeneration and overall growth potential of cold-stored stock at 0.5 and 5 C were comparable to those of spring-lifted controls. Seedlings totally enclosed in plastic-lined Kraft bags with moist peat surrounding the roots showed highest root regeneration capacity and lowest shoot water stress. Root regeneration capacity of all species examined was significantly correlated with shoot xylem water potential at time of removal from storage. First- and second-year survival and growth of out-planted red oak seedlings were significantly correlated to both root regeneration capacity and shoot xylem water potential at time of removal from storage.

Integration of methods to produce planting stock of high physiological quality with improved silvicultural techniques of site preparation and weed control appears highly promising in increasing survival and initial shoot growth of newly planted seedlings.

FIELD PERFORMANCE OF PLANTED OAKS

RED OAK GROWTH AFFECTED BY AGE OF PLANTING STOCK, MULCHING, TOP PRUNING, AND FERTILIZATION

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Survival and growth of planted northern red oak (*Quercus rubra* L.) seedlings on cutover forested sites were studied in relation to top pruning, fertilizing, age and size of seedlings at planting time, and method of artificial regeneration. Top pruning at planting time and at 1 and 2 years suppressed annual height growth, produced smaller diameter seedlings, and significantly reduced survival of 1-0 seedlings. Mulching in combination with top pruning did not significantly affect height growth or survival. Fertilizing with combinations of N and P, with and without plastic mulching, did not significantly affect growth of 2-0 seedlings in 5 years after treatment. The use of calcium cyanamide as a fertilizer herbicide did not significantly affect red oak seedlings. Direct-seeded acorns and 5- to 6-week-old tubelings were almost completely destroyed by rodents. If oaks are to be artificially regenerated, planting bare-rooted seedlings offers the best hope of success. Overall, 30 to 50 percent of the planted seedlings, regardless of treatment, averaged more than 6 feet tall at 7 years from seed. It is expected that many of those that are presently dominant or codominant will reach maturity in the new stand.

FIELD PERFORMANCE OF PLANTED OAKS

THREE-YEAR FIELD PERFORMANCE OF ENGLISH OAK PLANTED IN AN OZARK CLEARCUT

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Shoot growth of container-grown and 1-0 bare-root English oak (*Quercus robur* L.) was measured in an oak clearcut (black oak (*Q. velutina* Lam.) site index 70) in southern Missouri. Containerized trees were grown in 294 cc (30 in^3) Spencer-Lemaire Rootrainers during an 8-month extended growing season. Half of the fall-planted trees were mulched with 4-mil black plastic sheets 91 cm square. Initial size of seedlings by treatment and stock class averaged 52 to 57 cm in height and 5 to 8 mm in caliper 2 cm above the root collar.

During the first year in the field, shoot dieback exceeded shoot elongation for all treatments. However, significantly less (0.05 level) net shoot dieback occurred on unmulched container-grown seedlings (1.3 cm) than on unmulched bare-root seedlings (6.5 cm); mulching further increased dieback on both stock classes by an average of 10.2 cm. By the end of the third growing season, mean net 3-year shoot elongation ranged from 24 cm for mulched container-grown seedlings to 39 cm for unmulched bare-root seedlings. When treatment effects were adjusted for initial seedling caliper, positive effects of mulching were significantly associated with large caliper and negative effects with small shoot caliper. This effect was most prominent for containerized trees during the third growing season. Mean shoot growth of English oak was 2 to 2½ times that of planted black oak, white oak (*Q. alba* L.), and northern red oak (*Q. rubra* L.) in previous studies in the same area under similar environmental conditions.

ROOT DEVELOPMENT AND EARLY GROWTH OF RED OAK SEEDLINGS

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Root development and top development of containerized and bare-root stock of northern red oak (*Quercus rubra* L.) seedlings were studied under field conditions. A very strong correlation was found between first year top growth and root development (tap root was most important) of direct-seeded plants; a weaker correlation was found between first year top growth and root development (lateral roots were most important) of bare-root seedlings; and a very weak correlation was found between first year top growth and root development of container grown seedlings. Growth media in the containers markedly affected root growth and thus top growth after outplanting. This was apparently related to reduced moisture movement from fine-textured soil to the coarse-textured growth media. Two years after outplanting in a silty loam soil, seedlings produced in containers with a 50/50 mixture of Pro-Mix BX and a sandy loam soil had a significantly larger root system and larger tops than seedlings produced in Pro-Mix BX alone.

FIELD PERFORMANCE OF PLANTED OAKS

CONTAINER SIZE AND GROWTH MEDIA INFLUENCE EARLY GROWTH AND SURVIVAL OF SOUTHERN OAKS IN MISSISSIPPI

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Morphological characteristics of 12-week-old *Quercus pagoda* Raf., *Q. nuttallii* Palmer, *Q. shumardii* Buckl., and *Q. nigra* L. seedlings grown in combinations of various container sizes (0.5, 0.9, and 1.9 liter) and growth media (peat-perlite, and 1:1 peat-perlite and sandy loam soil) were measured to evaluate the effects of container size and media on their growth and development. Stem length increased with increasing container size with few significant differences in root-collar diameter. Seedlings in the peat-perlite media had greater leaf surface areas than those in the combination media. Significantly greater root/shoot ratios were found in the 0.5 liter containers with the combination media as compared to the other treatments due to significantly smaller stem lengths and leaf surface areas of seedlings in this treatment. Root weights differed little between treatments. The 0.9 liter containers with the peat-perlite media produced seedlings comparable to those in the 1.9 liter containers and was selected as the best container-media combination of the six treatments tested. The 12-week-old seedlings were outplanted on an Upper Coastal Plain site in east-central Mississippi in July, 1977 and survival and growth were measured after the first field season and 1 year after outplanting. Nursery-produced 1-0 bareroot stock of the same age and seed source as the containerized seedlings were outplanted in March, 1978 for field performance comparison. Containerized seedling survival was 98 percent 1 year after outplanting. However, severe deer browse negated growth in the first field season. Root-collar diameters attained during the first field season by seedlings in the 0.9 liter containers with the peat-perlite media were comparable to those of the 1-0 bareroot stock at outplanting.

FIELD PERFORMANCE OF CONTAINERIZED AND BAREROOT BLACK OAK

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and
G. S. Cox, *Professor,*
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University of Missouri,
Columbia, Missouri

Black oak (*Quercus velutina* Lam.) seedlings inoculated with *Pisolithus tinctorius* (Pers.) Coker and Couch were grown for one season in 750 cc Spencer-Lemaire containers in the greenhouse and in a nursery (noninoculated seedlings were also grown in containers and in the nursery for comparison). Examination before planting revealed that 38 and 45 percent, respectively, of the roots of the containerized and 1-0 barerooted seedlings were infected with *Pisolithus*. Barerooted seedlings were significantly larger than containerized seedlings. However, total root system length of the containerized seedlings was significantly greater.

One year following outplanting on two clearcut sites, 94 percent of the container-grown seedlings inoculated with *Pisolithus* had survived. Survival of the inoculated and noninoculated 1-0 barerooted stock was 63 and 70 percent, respectively. Root weight, shoot length and weight, and leaf area of inoculated containerized seedlings increased significantly during the first year. The inoculated and noninoculated barerooted stock suffered severe shoot dieback and a decline in leaf area. Percent infection with *Pisolithus tinctorius* declined on roots of all inoculated seedlings during the first field growing season. The length of both suberized and unsuberized (i.e., white) roots of the container-grown seedlings, especially those inoculated with *Pisolithus*, increased significantly. Few of the inoculated and noninoculated barerooted seedlings developed new roots and many of the lateral roots were dead.

Diurnal measurements of xylem pressure potential and leaf conductance indicated that container-grown seedlings inoculated with *Pisolithus* better avoided water stress during a moderate mid-summer drought than noninoculated seedlings.

GROWTH AND NUTRITION OF PLANTED ALLEGHENY HARDWOODS

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Warren, Pennsylvania

Research conducted in northwestern Pennsylvania during the past 5 years has shown that intensive browsing by deer as well as severe nitrogen and phosphorus deficiencies in the soil are inimical to the success of planted Allegheny hardwoods. Planted seedlings must be protected against browsing and must be fertilized if they are to survive and grow at acceptable rates.

Species/fertilizer experiments conducted with planted black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), sugar maple (*Acer saccharum* Marsh.), and yellow-poplar (*Liriodendron tulipifera* L.) show that black cherry outperforms these other species in survival and rate of growth. This is in part due to the exceptional juvenile growth potential of black cherry and also to the fact that black cherry is tolerant of late-spring freezes, which often kill back the tops of white ash and yellow-poplar seedlings to the root collar.

Field performance of fertilized and unfertilized bare-root, containerized, and natural black cherry seedlings located on clearcut forest sites shows that: (1) 18 grams of nitrogen and 2 grams of phosphorus broadcast over a 3-foot-diameter plot will satisfy requirements for these nutrients, (2) bare-root stock should be 60 to 90 cm tall to grow rapidly after outplanting, (3) containerization offers no advantage, and (4) it is far better to protect and fertilize natural seedlings than to plant.

OVERSTORY DENSITY, STOCK SIZE, AND DEER BROWSING AFFECT SURVIVAL AND GROWTH OF PLANTED RED OAK

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and
David A. Marquis, *Principal Silviculturist,*
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Lack of adequate oak advance regeneration in Pennsylvania is due mainly to loss of viable acorns to insects, rodents, and deer and of seedlings to deer. Poor survival and growth of planted seedlings in clearcuts and uncut stands led to this test of planting northern red oak (*Quercus rubra* L.) under three levels of overstory density (100 percent, 60 percent, and 30 percent stocked), using two sizes of nursery stock, with and without deer protection. After 3 years, the residual overstory trees were removed.

Survival did not differ between the large and small nursery stock, but the small stock had better height and diameter growth and appeared to respond better to release. Fenced seedlings had a significantly higher survival than unfenced seedlings. The effect of deer browsing was also shown by a decrease in the height of unfenced seedlings and a slower increase in diameter. Both fenced and unfenced seedlings responded to release, but the response was better for fenced seedlings. Survival, height, and diameter growth did not differ significantly between the 60 percent and 30 percent stocked plots, but all three variables decreased significantly for the 100 percent stocked plots. All plots responded to overstory release, but the 60 percent and 30 percent stocked plots respond more.

Protection from deer browsing is required for adequate survival and growth of planted red oak in Pennsylvania. Some type of shelterwood cutting with underplanting and protection of seedlings may be successful for regenerating stands that lack adequate advance regeneration.

FIELD PERFORMANCE OF PLANTED OAKS

PLANTING RESULTS ON THE CUMBERLAND PLATEAU

Charles E. McGee, *Project Leader and Principal Silviculturist,*
USDA Forest Service,
Southern Forest Experiment Station,
Sewanee, Tennessee

Results of 18 years of research on artificial regeneration of oak at Sewanee have been largely negative. In several studies using *Quercus alba* L., *Q. velutina* Lam., *Q. coccinea* Muenchh., and *Q. rubra* L., survival has been acceptable but growth and development have been poor. Thus, traditional planting methods do not appear to be the answer to regenerating oak. The oak planting outlook will continue to be bleak until breakthroughs are made that will allow planted oaks to compete with rapidly growing competition.

PROPAGATING TANOAK AND CALIFORNIA BLACK OAK ON A GOOD SITE IN NORTHERN CALIFORNIA

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Pacific Southwest Forest and Range Experiment Station,
Redding, California

A laboratory trial of California black oak (*Quercus kelloggii* Newb.) acorns showed much faster and more complete germination of acorns positioned point-up rather than point-down (34 vs. 47 days and 24 vs. 21 percent). Acorns positioned on their sides germinated even slower and less completely than those positioned point-down. A field trial (808 seedspots) of tanoak (*Lithocarpus densiflorus* (Hook- and Arn.) Rehd.) acorns also showed much faster and more complete germination of acorns positioned point-up rather than point-down (12 vs. 41 days and 53 vs. 21 percent).

Fertilization with ¼ pound of 16-20-0 and irrigation with about ½ gallon of water per seedling every 2 weeks during summer significantly increased height of young tanoaks. Water alone and fertilizer alone also significantly increased seedling height over the untreated control. Foliar analysis confirmed that nitrogen and phosphorus were significantly greater in treated seedling leaves. At the time of maximum nutrient stress (June 20), four of five macronutrients tested were near poverty values in untreated seedlings. Fertilized black oak seedlings were three times taller than unfertilized counterparts at age 5.

Average predawn moisture stress at time of maximum stress (September 4) was lower for tanoak seedlings receiving water alone or water and fertilizer combined. For California black oak, moisture stress was lower for fertilized seedlings. In another test, differences in diurnal fluctuation between a large (10-foot tall) and small (1-foot tall) 6-year-old tanoak seedling were minor. In a third test between tanoak and black oak seedling-sprouts in full sun or deep shade, duration of high stress was much longer for plants in full sun.

Outplanting tanoak and black oak seedlings in large containers and shading tanoak seedlings did not increase survival.

Ten-year seedling survival in field trials was 30 percent for tanoak and 41 percent for black oak. Height growth of all but fertilized black oak seedlings was poor.

Establishment of tanoak in conventional plantations appears difficult; California black oak shows some promise.

FIELD PERFORMANCE OF PLANTED OAKS

INSECTS AFFECTING SEED PRODUCTION AND THE GROWTH AND FORM OF SEEDLINGS AND SAPLINGS

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University of Missouri,
Columbia, Missouri

Data on insect damage were collected on 1,536 northern red oak (*Quercus rubra* L.) seedlings planted in an upland oak forest in southern Missouri. Seasonal activity and impact of insects were determined in relation to (1) growth and developmental characteristics of containerized versus bare-root nursery stock, (2) top pruning of seedlings versus no pruning prior to planting, and (3) planting after clearcutting versus underplanting. Bud loss and defoliation in 1978 and 1979 were attributed to nine microleps, several undetermined May beetles (*Phyllophaga* sp.), and click beetles (*Limoneus* sp.). In addition, the leaf cutting weevil (*Attelebus bipustulatus* F.) caused 75 percent defoliation in one clearcut plot and 20 to 50 percent in three other clearcut plots. The twig pruner (*Elaphidionoides villosus* (F.)) caused 6 to 20 percent seedling mortality in unclipped seedlings in clearcut plots in 1979. The Asiatic oak weevil (*Cyrtepistomus castaneus* (Roelofs)) caused from 25 to 100 percent defoliation among the clearcut plots in 1978. In contrast, 1979 defoliation from Asiatic oak weevils was sparse in clearcuts (<25) but ranged from 25 to 50 percent in the overstory plots. Laboratory studies further showed that Asiatic oak weevil larvae feed on oak roots and can severely reduce numbers of fine roots. The role of insects that cause bud, leaf, and root losses is a potentially important problem associated with oak planting.

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Contains abstracts of 26 papers given at the Seedling Physiology and Growth Problems in Oak Planting Workshop, held in Columbia, Missouri in November, 1979.

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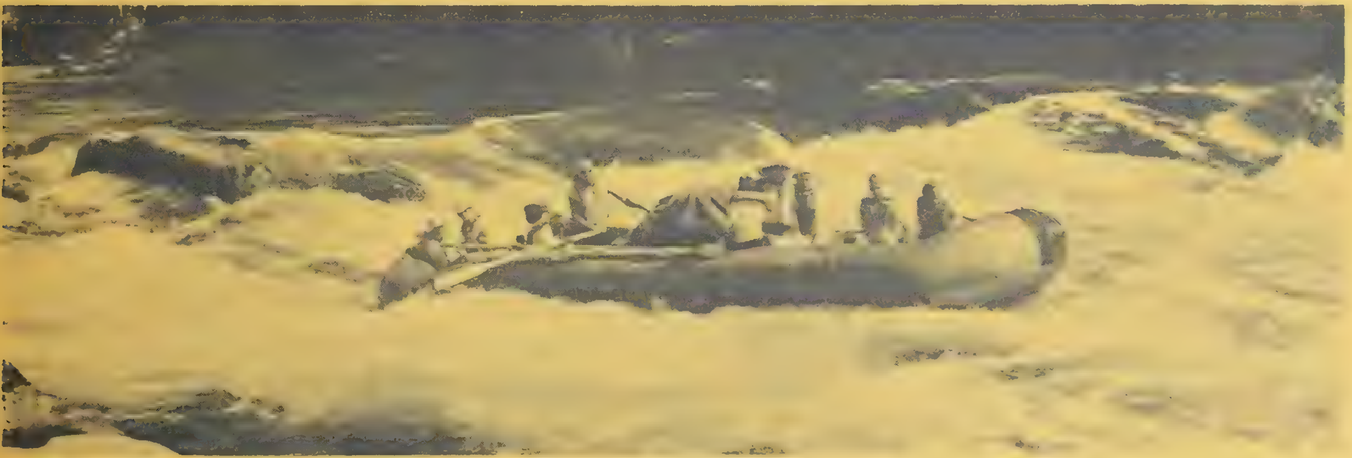
SOME RECENT PRODUCTS OF RIVER RECREATION RESEARCH



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SOME RECENT PRODUCTS OF RIVER RECREATION RESEARCH

Papers presented at the Second Conference on Scientific Research in the National Parks, November, 1979, San Francisco, California.

TECHNICAL COORDINATORS:

David W. Lime
North Central Forest
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and

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FOREWORD

The National Park Service and the American Institute of Biological Sciences sponsored the Second Conference on Scientific Research in National Parks, November 26-30, 1979 in San Francisco, California. More than 500 scientists and managers attended from local, State, and Federal organizations.

Included in the Conference were 18 sessions and 55 papers dealing with the sociological aspects of recreation behavior. The nine papers appearing here were presented during three of those sessions and focus on research into the sociology of river recreation. These papers do not cover the breadth of research in this area, but they are examples of current issues that concern researchers and resource administrators. The papers also reflect the growing base of knowledge in this emerging field of research.

David W. Lime, Project Leader for the Backcountry River Recreation Management and Research Project of the North Central Forest Experiment Station, was program organizer and chairman for these sessions. Donald R. Field, Associate Regional Director for Science and Technology, Pacific Northwest Region, National Park Service, was general chairman for the Sociology Program at the Conference.

The papers are printed here essentially as submitted by the authors except for some minor copy editing to assure uniformity of style.

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HIGHLIGHTS

The sociology sessions of the National Park Service Second Conference on Scientific Research focused upon research undertaken on local, State, and Federal land—both terrestrial and aquatic environments—that has implications for Park Service management. The nine papers presented here pertain to four interrelated issues: (1) the potential of a nationwide data base that can describe patterns of recreational use as well as the characteristics and preferences of recreationists among river environments; (2) the development of research methods to measure elements of the outdoor experience, such as recreational satisfaction and site attraction or "demand" for river settings; (3) the resolution or better understanding of critical topics facing administrators, such as allocating use to the commercial and private sectors, social carrying capacity and displacement of recreationists within and between river environments, and the suitability of river settings and activities to satisfy the diverse preferences and tastes of the recreating public; and (4) the application and use of social science research to solve practical problems.

The paper by Lime, Knopf, and Peterson discusses the potential value of viewing rivers regionally or nationally as a system and the subsequent need for baseline information on how rivers are used and by whom. They propose a program of long-term cooperative research on river recreationists nationwide to develop and apply standardized survey methods for describing patterns of behavior, characteristics, and management preferences of recreationists.

The papers by Ditton, Graefe, and Fedler and by Peterson, Lime, and Anderson discuss ways to measure the illusive concepts of recreational satisfaction and site attraction or demand. Ditton *et al.* present an attitude scale that samples and quantifies overall satisfaction. Specific components of satisfaction also are identified. Findings suggest that satisfaction is best measured by a scale that includes innovative as well as more customary general statements. Findings also support the notion that overall satisfaction is influenced by satisfaction with particular aspects of the experience.

Peterson *et al.* address the processes by which people choose between and among recreational sites in pursuit of leisure activities. Site attractiveness and site "demand" modeling are useful methods of analysis. The first topic is illustrated by a simple distance-decay model, applied conceptually to lottery rationing and empirically to several rivers. The second topic is illustrated by applying a logit model to several rivers. Finally, theory is presented to clarify conditions in which single-site analysis is valid and to identify the kind of model needed if specific rivers are to be managed as part of a nationwide system of river recreation opportunities.

Papers by Utter, Gleason, and McCool, by Becker, Niemann, and Gates, and by Schreyer and Roggenbuck present the results of recent studies of the concepts of recreational use allocation, displacement, and substitutability. Utter *et al.* explore the highly controversial process of allocating use between commercial and private sectors on whitewater rivers. In a study of actual and potential river floaters on the Middle Fork Salmon River, Idaho, a lottery rationing method was preferred by private users and people not receiving a permit. The advance reservation method was favored by commercial users. No relation was found between the individual's stress release/escape motives and their preferences for allotment and rationing techniques.

Surveys by Becker *et al.* during 1977 and 1978 on the Lower St. Croix and Upper Mississippi Rivers examined the hypothesis that no inverse relation exists between actual user density, crowding, and satisfaction. When each of the study rivers was viewed individually, no relation between density, crowding, and satisfaction was found. However, when viewed as a system, it was discovered that a portion of users from the Lower St. Croix, who were sensitive to its high use levels, were now on the Mississippi. Also, the aggregate user population on the Mississippi was more sensitive to user density than the aggregate Lower St. Croix population. Users were apparently dividing themselves between the two rivers: those users seeking high interaction were using the Lower St. Croix and those seeking low density experiences were using the Mississippi River. Those Upper Mississippi recreationists who formerly used the Lower St. Croix cited crowding as the dominant reason for moving. It is suggested that changes in a resource component may alter the user population on the site and will affect the entire resource system by displacing users who are no longer satisfied with their experience.

Schreyer and Roggenbuck suggest that National Parks are symbols of cultural values. Their study in dinosaur National Monument explores the extent to which visitors to a Park Service area hold tangible images of the meaning and purpose of National Parks and the relation of this image to a person's background, on-site behavior, attitudes concerning the use of such places, and preferences for Park Service management schemes. Two research issues are addressed: (1) the relation between social definitions of recreation places and behavior, and (2) the feasibility of identifying a primary park clientele for decisionmaking.

The papers by Shelby, Jensen, and Chilman consider the use of social science in the management and planning process. Research by Shelby in this area suggests two things. First, complex decisions that use research results are likely to be untidy and "interactive, rather than rational and linear". Second, a number of political factors may affect research utilization. He presents a study of sociological issues and research in Grand Canyon National Park, Arizona that shows a complex decisionmaking process supporting the interactive view. The study also is used to develop a number of "principles" that show how political factors affect utilization.

Jensen notes that social science research is a tool for management when examining policy issues, but such information is not necessarily the basis for establishing or implementing policy. Social science can aid in guiding policy, such as establishing social carrying capacity or providing alternative scenarios about the relation of various use limits to experience factors.

Chilman *et al.* describe a research program designed to gather basic data for determining recreation carrying capacity on Ozark National Scenic Riverways in Missouri from 1972 to 1977. The results of the research were widely distributed to interested publics before hearings in 1979. A management decisionmaking model was developed that incorporated the results of the research.

One of the conclusions from the Conference was that the future of social science research in support of resource management hinges upon the accumulation of national and regional data. Once established, the data base could provide the foundation to determine whether management concerns and issues associated with a specific site require additional research. If research is required, the data base can be a guide to define the questions or issues to be tested. Such information might likewise provide trend information on changing patterns of recreation use, changes in the composition of user populations, and provide comparisons in recreation use between Forest Service, Park Service, and Bureau of Land Management areas. Changes within a given recreation area can likewise be monitored. Finally, a national and regional data base might well provide the basis upon which management objectives and policies are examined, leading to a more effective resource management policy.

It would be difficult for any one agency or single scientist to generate such a data base. Therefore, a joint research effort, such as that emerging on river recreation between the Forest Service, National Park Service, Bureau of Land Management, and the Tennessee Valley Authority, has merit. The Second Conference on Scientific Research in the National Parks served as a significant forum to foster communication for joint research and the benefits which can derive from its undertaking.

THE NATIONAL RIVER RECREATION STUDY: GROWING NEW DATA BASE WITH EXCITING POTENTIAL

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Evanston, Illinois

The National River Recreation Study is a nationwide survey of river recreation use with a time horizon of at least a decade. The primary goal is to describe characteristics and preferences of recreational users for a variety of rivers using standardized measurement instruments. A secondary goal is to describe the Nation's spectrum of river recreation opportunities, and then to identify a set of rivers representative of that spectrum. This set then can be used in future research to monitor change in the character of national river recreation use (Knopf and Lime 1979).

Impetus for such large-scale study arose simultaneously from resource managers and the research community. Managers needed an efficient mechanism for documenting user preferences before they could develop river management plans. Managers also were contending with emerging problems of use conflicts, depreciative behavior, rationing of resources, and environmental impacts. The appeal for basic information was widespread across resource management agencies at federal, state, and regional levels (USDA Forest Service 1977).

At the same time, the research community saw the need to counter a trend toward isolated, noncomparable case studies in river management (Hecock *et al.* 1976). There was a call for standardized methodology and systematic, coordinated inquiry of national scope to allow comparisons both in time and between resources.

THE NEED FOR INFORMATION

Our Nation's waterways have experienced a tremendous increase in recreational use in the last decade. Every indication is that this upward trend will continue (Hecock 1977). Public concern for proper planning and management of waterways has accompanied this increase. Evidence of this concern is the voluminous public input associated with river management plans on specific rivers and with studies of rivers for inclusion in the National Wild and Scenic River System as well as state programs (Eastman and Brown 1979, Priesnitz 1979).

Both environmental and social problems have been created by increased numbers of river recreation users. Experience has shown that the most serious problems generally involve the management of people and their behavior (Carothers *et al.* 1976). More is known about the physical and environmental problems and their solutions than the social ones. Recreation planners and managers often have been forced to make decisions on intuition and "best guess". Identification of specific management problems, the planning of facilities, development of regulations and public information programs, environmental impact statements, prediction of use patterns, and classification studies would all be aided by better data on river recreation use.

Not only have public resource administrators and planners recognized the need for information on river recreation use and users, the legislative branch of government has mandated the collection and use of such information for decisionmaking. In the Forest Service, for example, the importance of knowing how river (as well as other) environments are used and by whom and monitoring change over time is acknowledged in the 1974 Forest and Rangeland Renewable Resources Planning Act (RPA). This legislation was amended by the National Forest Management Act (NFMA) of 1976 (16 U. S. C. 1600). Regulations published in October 1979 for implementing provisions of the NFMA clearly specify such information is required, not only to plan and implement programs, but to evaluate the effectiveness of these activities as well (Federal Register 1979). The Bureau of Land Management also needs such information on river recreation use to implement the Federal Land Policy and Management Act of 1976 (43 U. S. C. 1701).

Growth in numbers of river recreation studies has paralleled the growth of river recreation use, public interest in preserving resources, attendant management problems, and legislation calling for greater specificity in land use planning and management. The recent review by Anderson *et al.* (1978) lists nearly 100 studies relating to the identification of river use and users. Since that publication, more than 30 documents on this subject have been published.

Unfortunately, most studies of river use and users have been one-time efforts without follow-up inquiry. Most have been one- or two-river case studies of short duration, usually one season. Each study typically has used a different survey instrument, and many studies have been poorly designed in terms of limited sample size, representativeness, and methodology. As a result making comparisons both among rivers and across time has been virtually impossible. And, much of the research has been funded and/or encouraged by land managers who frequently want one-time, one-river, single activity, descriptive studies that reflect local conditions. Seldom has research been funded to systematically study regional, even basin-wide rivers as a system so recreation uses can be better planned and allocated to reflect the mix of experiences desired by the public (Lime 1977).

THE RESEARCH FOCUS

What sets this program of research apart from many others is the application of standardized data collection instruments over a variety of river environments nationwide. This permits a much needed regional and national perspective and allows for the monitoring of change. Accordingly, the study interests both resource administrators and researchers. It serves not only the needs of local resource planners and managers but also will yield insight into the dynamics of supply and demand for river recreation opportunities nationally.

The target population is people who travel on rivers or streams by raft, canoe, kayak, motorboat, innertube or some other conveyance. Stationary river recreationists such as fishermen, swimmers, shore users, and riparian landowners are not the focus of the study. However, the general scope of the research and many of the conceptual issues addressed could be applied to these populations.

To meet the intent of this research the following objectives were established.

1. Develop survey instruments to obtain the following:
    a. Level of satisfaction with the river experience.
    b. Reasons for using the river as a recreational resource.
    c. Number, severity, and kinds of problems experienced by users while recreating.
    d. Reactions to numbers of people encountered.
    e. Perceived conflict between different types of river users.
    f. Perceived degree of environmental impact arising from recreational use of the river.
    g. Degree of support for specific management practices.
    h. Characteristics of the user: age, occupation, education, physical impairment status, amount of prior use of river stretch, and nature of prior experience in recreational use of rivers.
    i. Characteristics of the trip: access points used, mode of travel, length of trip, party size, timing of trip (weekend vs weekday), river stretch used, craft ownership (private vs commercial), type of group (e. g., family vs organization), and time at which decision to visit the river was made.
    j. Demand for the river resource, in terms of both absolute numbers of users and willingness to pay for the experience.
2. Apply the instruments to representative samples of recreationists on a variety of rivers nationwide.

3. Develop a data processing system capable of offering immediate, cost-efficient summarization, interpretation, and dissemination of the data to resource planners and managers.
4. Make within- and cross-resource analyses to describe, from a national perspective, the character of supply and demand for river recreation, determinants of a quality experience, significant problems in river management, and viable solutions to these problems.
5. Identify a set of river stretches representative of the Nation's spectrum of river recreation opportunities that can be used in future research to monitor change in the character of national river recreation use. Follow-up studies would be made at 3- to 5-year intervals.

To meet study objectives, it is important to consider a broad range of river recreation opportunities. Rivers are selected for study based on the following criteria: (a) The spectrum of river recreation opportunities available nationwide is represented, ranging from whitewater to flatwater, urban to backcountry, and multiple-day to brief excursions, (b) A range of geographic areas within the contiguous United States and Alaska is represented, (c) Different types and levels of recreation use are represented, (d) Different kinds of river management problems and issues are represented, and (e) Management agencies for the study rivers are interested and cooperative.

PROGRESS THUS FAR

The National River Recreation Study has developed over a 5-year period. Several universities cooperated in this development, and there have been formal working relationships with representatives of the Bureau of Land Management, Forest Service, Tennessee Valley Authority, National Park Service, and several natural resource management agencies of individual states. Resource managers have had a significant role in the formation of this study—in calling for its creation, in setting study objectives, in creating content of the instrumentation, in selecting study environments, and in establishing procedures for analysis and information dissemination.

Survey instruments or proto-types developed through cooperative research have been applied nationwide (fig. 1). Since 1977, 39 different rivers or

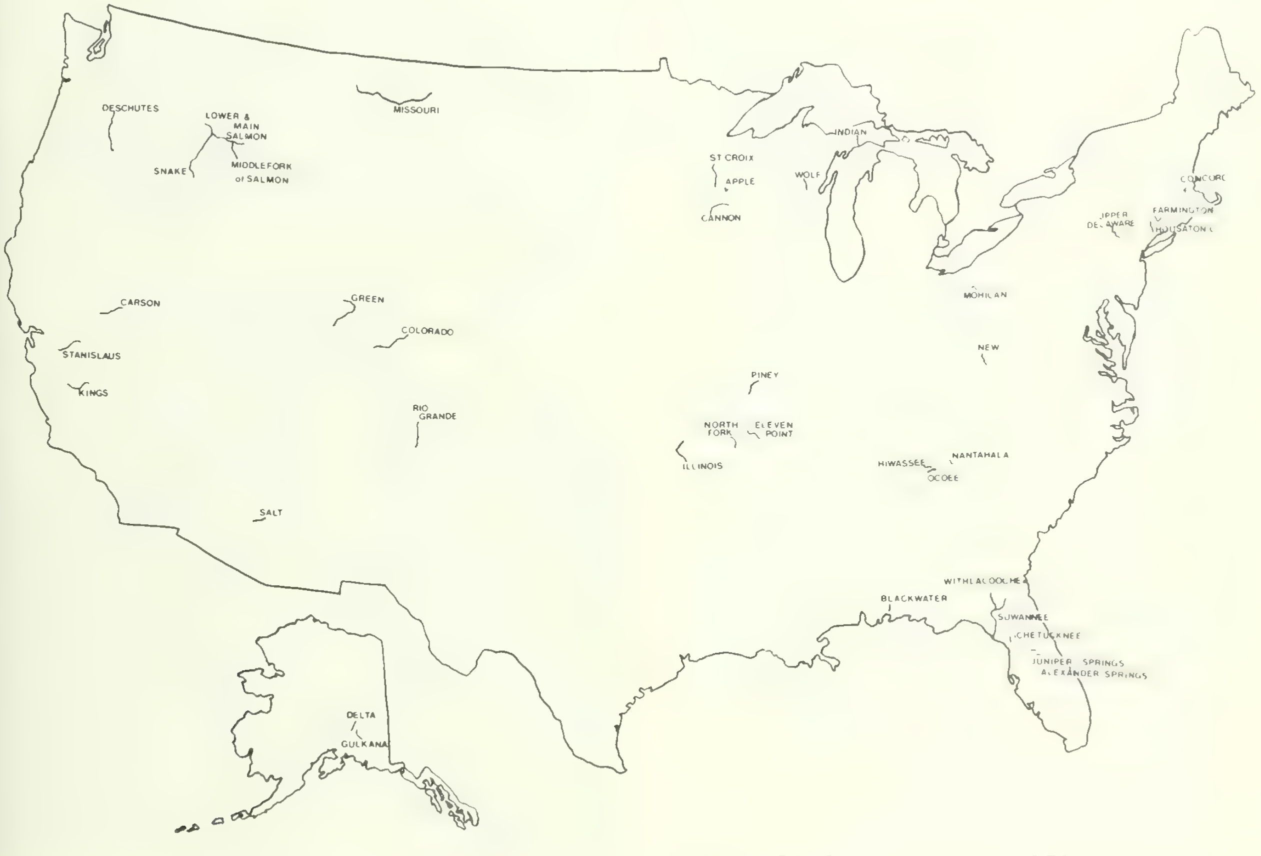

Figure 1. —*The National River Recreation Study- Sites: 1977-1979*

river stretches have been studied: 11 were studied in 1977, 13 in 1978, and 23 in 1979. Five rivers were studied more than one use season (table 1).

Table 1.—*River stretches included in the National River Recreation Study: 1977-1979*

Year	River	State	Management Agency
1977	Apple	WI	State
	Colorado	CO	BLM[1]
	Deschutes	OR	BLM
	Hiwassee	TN	TVA[2]/FS[3]
	Illinois	OK	State
	Middlefork Salmon	ID	FS
	Missouri	MT	BLM
	Mohican	OH	State
	Nantahala	NC	TVA/FS
	Ocoee	TN	TVA
	Salmon, Main	ID	FS
1978	Cannon	MN	State
	Colorado	CO	BLM
	Eleven Point	MO	FS
	Kings	CA	FS
	Missouri	MT	BLM
	North Fork	MO	FS
	Ocoee	TN	TVA
	Piney	MO	FS
	St. Croix	MN/WI	NPS[4]
	Salt	AZ	FS
	Snake	ID/OR	FS
	Stanislaus	CA	BLM
	Wolf	WI	State
1979	Alexander Springs	FL	FS
	Blackwater	FL	State
	Carson	NV	BLM/FS
	Colorado	CO	BLM
	Concord	MA	State
	Delta	AK	BLM
	Deschutes	OR	BLM
	Farmington	CT	State
	Green	UT	FS
	Gulkana	AK	BLM
	Housatonic	CT	State
	Ichetucknee	FL	State
	Indian	MI	FS
	Juniper Springs	FL	FS
	Missouri	MT	BLM
	New	WV	NPS
	Ocoee	TN	TVA
	Rio Grande	NM	BLM
	Salmon, Lower	ID	BLM
	Stanislaus	CA	BLM
	Suwannee	FL	State
	Upper Delaware	NY	NPS
	Withlacoochee	FL	State

[1] Bureau of Land Management.
[2] Tennessee Valley Authority.
[3] Forest Service.
[4] National Park Service.

THE DATA COLLECTION INSTRUMENTS

There are two phases of data collection on each study river. In the first phase, recreationists are interviewed briefly at access points to obtain basic information on the nature of their visit. Each person 16 years of age and older completes a form distributed by an interviewer. About one minute is required per person to complete the on-site interview. The interviewer then talks with one member of the group to characterize the group's trip as a whole.

These on-site interviews provide information about length of stay, number and type of watercraft used, number in group, entry and take-out points, prior experience of users in visiting the river, and the degree to which the visit was a primary purpose of their trip away from home. Names and addresses also are obtained for the second phase of the study in which selected individuals are sent a questionnaire.

A sufficient number of sample days are chosen on each river to (a) ensure representation of the total use character during the season of interest and (b) secure interviews with approximately 1,500 recreationists per river stretch. For rivers receiving low usage, required sample sizes are reduced accordingly.

In 1977, 1978, and 1979 approximately 12,700 groups and 50,500 individuals were interviewed at river accesses on 39 different rivers. On many of the rivers administered by a public agency (especially the Bureau of Land Management), data was collected by agency personnel. For those resources where such assistance was not available, we provided the necessary field technicians and supervision.

In the second phase, questionnaires are administered by mail to a representative sample of recreationists interviewed on-site. For statistical reliability and requirements of scaling (Nunnally 1967), at least 200 usable returns per study area are required. Based on an estimated usable return of at least 60 percent, a sample of 350 people per study area are mailed the questionnaire. Questionnaires are sent within 8 weeks of the on-site contact following the methodology recommended by Dillman (1978). Two follow-up mailings are sent to nonrespondents at 3-week intervals. The second mailing includes an additional copy of the questionnaire. Approximately 20 minutes is required to complete the questionnaire.

The questionnaire has undergone a developmental process over 4 years beginning in 1976. The form now in use draws heavily from an instrument developed and used in cooperation with Northwestern University. That questionnaire was derived in part from several studies, with particular emphasis on cooperative research on the Colorado and Green Rivers (Schreyer and Nielson 1978).

From the 50,500 individuals interviewed on-site at 39 rivers in 1977, 1978, and 1979, nearly 16,000 have been sent mail questionnaires. A response rate of 56 percent was achieved for the 1977 sample compared to 73 percent in 1978. The differences in response reflect in part an improvement in the efficiency of the questionnaire and in mailing and follow-up procedures.

THE DATA BASE

The last 3 years of data collection have provided a large, broad-based and diverse information set capable of answering a variety of questions of interest to both resource administrators and researchers. Analyses are proceeding along two fronts. First, an outgrowth of Study Objective 3, is the development of basic tabular summaries of visitor characteristics, preferences, and opinions geared to the information needs of the appropriate river planners and managers. Second, and related to Objective 4, is the concern with theoretical, conceptual inquiries related to the issues of recreation "demand," choice and selection processes, and dimensions of satisfaction and a quality recreational experience. From these two activities, it will be possible to pursue a third activity, time series and cross-resource comparative analyses.

Basic Summaries for Planning and Management

Resource administrators have had a pivotal role in helping to identify what information is needed and how it should be presented. Basic descriptive data corresponding to the kinds of issues outlined under Study Objective 1 (a-j) seemed important; and, simple frequency distributions of visitor response to each question and basic statistics such as mean scores and standard deviations are prepared for appropriate questions for each river. Another primary undertaking has been to develop standardized tables and display formats to summarize user response to a number of issues identified as central to more effective decisionmaking. The data system allows fast retrieval of information, and many of the tables are prepared for distribution directly from the computer.

Approximately 50 tables have been developed, and they follow the issues outlined in Study Objective 1. Many of them provide the opportunity for field administrators to compare characteristics of specified subpopulations (such as first-time vs repeat visitors, private vs commercially outfitted groups, rafters vs kayakers vs canoeists, high solitude orientation vs low solitude orientation, day users vs overnight visitors and local residents vs users who travel a considerable distance to visit the river) along any of the parameters from the on-site interview or the questionnaire. In addition to the attendant cost efficiency of the standardized tables, the system structures the data into forms ready for field use and interpretation.

Information can be displayed for one river or compared for several rivers. For example, one question addressed in the mail questionnaire focuses on the number, severity, and kinds of problems visitors experienced during their trip. Using the data processing system, the manager can extract a profile of the perceived problems of the river in comparison with any other river or rivers in the data base. This can reveal strong points as well as weak points which may require management attention. Specific facts can also be retrieved, such as the proportion of individuals reporting that someone in the group received an injury. This would allow a partial assessment of potential safety problems; and, cross tabulation with variables such as composition of the group, size of group, and time of year the visit was made might reveal some contributing factors which, in turn, could help to focus management attention.

Theoretical Issues in Recreation Behavior

Beyond providing basic summaries of user characteristics and opinion, the data set is a rich and growing resource for examining a variety of methodological and theoretical issues in recreation behavior. This is not to say resource administrators will be uninterested in such information. On the contrary, the products of multivariate analyses and a better understanding of processes contributing to recreation behavior and visitor satisfaction add substantially to more complete and effective decisionmaking. The five topics which follow provide only a sampling of the potential.

Predictors of user satisfaction

A basic dependent variable included in the mail questionnaire is perceived quality of the river trip.

Respondents describe how strongly they agree or disagree to a variety of statements about feelings toward a river trip. Responses are subjected to cluster analyses to identify dimensions along which this variable should be defined (e.g., quality of social experience, quality of management, etc.). Then, the focus is on identifying predictors and intervening forces which affect the perceived level of quality along each dimension. Possible predictors include: reasons for making the trip; problems experienced during the trip; amount and kinds of encounters with other river users; prior experience; and, other characteristics of the trip and user.

Segmenting user populations on the basis of desired outcomes

Research has shown that within specific populations of recreationists, substantial diversity among individuals can exist in terms of experiences sought (Driver 1976). The basic tenet is that recreationists seeking different experiences react differently to particular environmental features, find different sources of satisfaction, and assign different priorities to alternate management strategies. Using object typing methodology (Nunnally 1967, Tyron and Bailey 1970), specific river populations are stratified into groups differing in reasons for using a river. Then, differences between groups in user characteristics and management preferences are explored. Such segmentation approaches are common to market research (Frank *et al.* 1972) and provide more realistic accounting of the diversity of demand (Shafer 1969).

Crowding and displacement

Defining the social carrying capacity for river recreation resources is an elusive, but necessary task of management (Lime and Stankey 1971). One ingredient in carrying capacity calculation is visitor response to existing use levels. The literature suggests that crowding perception is related to use density, behaviors encountered (Stankey 1973), expectations (Schreyer *et al.* 1976), motives (Roggenbuck and Schreyer 1977), method of travel (Heberlein 1977), and characteristics of the user. Each of these elements is measured in the mail questionnaire; and, the effects of each of these variable sets are explored simultaneously through multivariate analyses.

Of further concern is the relationship between level of perceived crowding and willingness to return to the river. It has been hypothesized that as resources become more popular, crowd-sensitive users are displaced by those favoring more socially-oriented experiences (Hendee and Campbell 1969, Clark *et al.* 1971). While this process has been described in theory, there are few existing empirical analyses (Nielsen and Endo 1977).

Demand Functions

Using travel-cost methodology (National Academy of Sciences 1975), trip demand functions are derived for study rivers (the focus of another paper in this Proceedings). A data base is formed by response to the "Zip Code" and "Purpose of trip" questions from the on-site interview. Creation of these functions allows: (a) evaluation of the national versus regional versus local significance (b) comparison and classification of rivers according to their ability to attract visitors, (c) explanation of the "attractiveness" of rivers for recreational use in terms of measurable and manageable features of those rivers, and (d) valuation of the recreational use of rivers.

Correlates of the desire for management action

Research has shown river recreationists can differ in their opinions about the appropriate roles of resource managers (Schreyer *et al.* 1976). Several questions in the mail questionnaire provide measure of the degree to which respondents believe the character of use on the river should be regulated. Characteristics of those in favor of management intervention are compared with those opposed to it. Further, the relative role of on-site experiences (as measured by visitors' perception of the kinds and severity of problems experienced while on the trip) in influencing the desire for management action is explored. From such analyses, managers will be able to understand specific sources of pressure for action, both in terms of the clientele which call for it and the conditions which precipitate it.

The Potential for Trend Analysis

Because the study encompasses at least a 6-year sampling frame, beginning with the 1977 use season and extending through the 1982 use season, it will be possible to describe use and users for a wide variety of river conditions and environments, and to prepare a foundation for documenting change. This wide assemblage of information will provide the needed empirical base for selecting a representative core of rivers for future time series analysis. It is anticipated followup studies would be made at 3- to 5-year intervals. Of course, rivers other than the set of core rivers could be studied to aid in answering specific management questions. And, other types of rivers could be added to the core set as more is learned about what constitutes variability.

The specific dimensions along which to define a representative set of rivers will be empirically determined. A variety of multivariate techniques will be used to identify variables which best distinguish among rivers such as geographic locale, resource attributes, use character (kind and intensity), existing management problems, and experiences desired by users. The core set identified for time series analysis will be the minimum number of rivers necessary to adequately represent the spectrum of river recreation opportunities available nationwide.

Data collected through trend analysis should be valuable not only to the research community but to planners and managers as well. For example, such information will provide local administrators with insight into changes in use patterns as well as change in the characteristics and preferences of river users. Additionally, time series and cross-resource comparative analyses will provide social scientists, planners, and others a coordinated, systematic investigation into possible changes from a river basin, regional, as well as national perspective.

CONCLUSION

Several valuable products are emerging from The National River Recreation Study (1) a large and diverse data base, (2) improved data collection instruments and procedures, and (3) capability for time series and cross-resource comparative analyses. We also have developed standardized tables and data retrieval procedures for use by resource administrators and are progressing with conceptual and theoretical analyses. The research also has produced a rich interaction between researchers and managers which has improved the capability of both.

An especially rewarding product of this research so far has been the training and educational benefits resulting from the interaction among participants. Over the past 3 years especially there has been a rich, and sometimes intense, dialogue between researchers and resource administrators in setting study objectives, in creating content of the data collection instruments, in selecting environments for study, in developing sampling frameworks and procedures for field data collection, and in developing alternative strategies for analysis and information dissemination.

This dialogue and interaction has done much to increase the capability of all parties involved—and accordingly the overall quality of the research. As researchers, we have gained a greater familiarity and appreciation of the on-site problems of administrators as well as a clearer understanding of specific information needs required to effectively improve decisionmaking. On the other hand, resource administrators hopefully have gained some insights into what the products of social science research can and cannot do to solve the complex and ever-growing problems. We trust this interaction will promote and foster continued cooperation and contribute to a better understanding of river recreation management. Through this process the public will be the ultimate beneficiary.

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RECREATIONAL SATISFACTION AT BUFFALO NATIONAL RIVER: SOME MEASUREMENT CONCERNS

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Satisfaction in recreation has typically been regarded as a goal of recreational resource management. The National Park Service (NPS) organic legislation and subsequent policy statements identify visitor enjoyment and benefits as a major product of NPS management. Indeed, as Schreyer (1976) pointed out, the phrase "for the benefit and enjoyment of the people" has acted as an invisible hand to shape and guide Park Service policy.

High satisfaction in park settings is now reported regularly. This high level of satisfaction does not appear to vary with individual characteristics, expectations, places, or activities (Holland 1979). This fact has often puzzled researchers who were trying to find support for a hypothesized relation between satisfaction and some other variable (most notably, user density). It has proven even more frustrating to resource managers waiting in vain for their studies to document "problems" they thought existed.

Consistent reports of high satisfaction have led to some thought-provoking theoretical discussions of why this is so. One school of thought suggests that it is not surprising to find many people reporting high satisfaction with their leisure activities because they have freely chosen these activities to provide satisfaction (Heberlein and Shelby 1977). Cheek and Burch (1976) suggest that, because leisure is spontaneous and connotes a sense of individual freedom, either there may not be any preconceived expectations to fulfill or the expectations may be fluid and adjustable. Schreyer[1] elaborates on the psychological mechanisms that may yield reports of high satisfaction: (1) individuals may **shift their perceptions** of the experience away from original evaluations in order to maintain the desired experience, (2) individuals may **shift their priorities** of expectations to maintain satisfaction, or (3) individuals may **change their behavior** to achieve preferred outcomes that have not been attained during previous occasions.

Reports of high satisfaction have prompted others to question the usefulness of the satisfaction concept. Heberlein (1977), for example, suggests that satisfaction alone is not a suitable criterion for management because high satisfaction levels can be found even when the character of the experience changes. He proposes a normative explanation for the observed lack of a relation between user density and satisfaction. Nielsen *et al.* (1977) similarly suggest that studies may show high levels of satisfaction regardless of the total level of use because the many new users to a given area have no pre-established norm regarding acceptable levels of contacts and therefore establish the use level they find on their first visit as their norm against which satisfaction judgments will be made.

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[1] *Schreyer, Richard M. 1979. Succession and displacement in River Recreation. 45 p. Paper prepared for River Recreation Project, North Central Forest Experiment Station, USDA Forest Service, St. Paul, Minnesota.*

Much research has been conducted to describe the nature of recreational satisfaction. Although a variety of approaches have been taken, several common elements can be identified in the definitions and conceptualizations of satisfaction found in the literature. Most studies that have discussed the theoretical background for recreational satisfaction have turned to the more fully developed job satisfaction literature and have concluded that discrepancy theory offers the most promising explanation (Greist 1968, Roggenbuck 1975, Graefe 1977, Holland 1979). First, discrepancy theory suggests that satisfaction is determined by the differences between the perceived outcomes a person receives and the outcomes one wants or thinks he should receive (Lawler 1972).

Second, discrepancy theory suggests that overall satisfaction in any situation is influenced collectively by the discrepancies that exist for each facet of the situation (Lawler 1972). The idea of specific satisfactions adding up in some way to produce total satisfaction (i.e. multidimensionality) is also well documented in the literature and thus seems to be a second common denominator in both theoretical and popular discussions of satisfaction (Bultena and Klessig 1969, Peterson 1974, Hendee 1974, Nielsen *et al.* 1977).

The measurement of satisfaction, however, has apparently lagged well behind its theoretical development. Some authors, recognizing the multiple components of satisfaction, have focused on some specific potential sources of dissatisfaction such as crowding or conflicts between users (e.g. Stankey 1973, Bassett *et al.* 1972). Another typical approach has been to ask recreationists to indicate overall satisfaction with their experience (e.g., Graefe 1977, Holland 1979, Roggenbuck 1975). The latter approach has produced the high satisfaction reports discussed earlier. Self reports of the importance attached to specific recreation outcomes or motivations have often accompanied such overall satisfaction ratings and have been interpreted as representing the dimensions of the experience that contribute to satisfaction. However, few studies have attempted to analytically relate specific satisfaction measures (i.e., the degree to which specific outcomes are attained) to overall satisfaction measures in a predictive sense (Greist 1968, Nielsen and Shelby 1977, Peterson 1974, Graefe 1977, Holland 1979). These latter studies have supported the notions of discrepancy and multidimensionality introduced earlier. However, the authors of these studies have generally concluded that the explanation of overall satisfaction available from specific satisfactions is insufficient and should be the topic of further research. Given that satisfaction reports from users tend to be high, it is still important for researchers to attempt to formulate the mechanisms of satisfaction and to empirically identify those variables that contribute to an explanation of satisfaction.

We feel that one reason for the inadequacy of past satisfaction studies is that little attention has been devoted to measuring the dependent variable—overall satisfaction. The usual procedure has been to ask recreationists some form of the question, "How did you enjoy your experience?" (Nielsen *et al.* 1977) and to use this single item as an indicator of satisfaction. This procedure is vulnerable because a single item offers no indication of validity or reliability. The consistency noted in past findings suggests these measures may be reliable, but the question of exactly what is being measured by these indicators remains unanswered.

Conventional Likert (summated rating) attitude scaling techniques have been used extensively to overcome this deficiency in the measurement of specific outcomes sought through recreation (e.g. Knopf 1972, Driver 1976), but these techniques appear to have been overlooked in measuring satisfaction itself. The intent of such scaling is to sample the domain of the construct being represented and measured. Herzberg *et al.* (1957) point out that differently worded questions that appear to measure the same thing can yield different results because different levels of feeling about the same subject may be tapped. If this is true, results of studies on satisfaction may be partially an artifact of the questioning used to measure satisfaction. Consequently, researchers must assess this possibility by generating multiple-item scales that quantify overall satisfaction with a known degree of reliability and comparing the performance of such scales with the types of single indicators that have typically been used.

Our first objective was to generate a multiple item attitude scale that would reliably sample and quantify the domain of overall satisfaction. Then, our second objective was to use this scale to identify the relation between specific aspects of satisfaction and the resultant measure of overall satisfaction and to compare the performance of the satisfaction scale measure as a dependent variable representing overall satisfaction with the performance of the individual scale items as dependent variables.

METHODS

The data set used to address these objectives was provided by a survey of Buffalo National River (BNR) floaters conducted during the summer of 1979. Eleven 3-day interview periods were selected between May 15 and August 15. Each day of the week was uniformly covered during the 3-month interview period.

Upon completion of the river trip, one member from each float group sampled (n = 805) was interviewed and then asked to complete a questionnaire. Each respondent answered questions designed to measure satisfaction with regard to both general (e.g., I thoroughly enjoyed the trip) and specific (e.g. I wish there had been more rapids) aspects of his or her river trip. Satisfaction statements were derived from a 14-item satisfaction scale developed by the River Recreation Research Project of the North Central Forest Experiment Station for use in their 1979 National River Recreation Study. Five general statements dealing with overall satisfaction were selected from the 14-item scale as potential overall satisfaction scale items because of their intuitive general meanings. An item analysis including calculation of item-total correlations and Cronbach alpha was conducted on the five items to identify the best combination of scale items.

To understand how well overall trip satisfaction could be explained in terms of its identifiable components, multiple regression was used with the overall satisfaction scale and its five component items as separate dependent variables. The independent variable pool included: (1) statements concerning satisfaction with specific elements of the float trip, measured on a 5-point (strongly disagree to strongly agree) response format; (2) statements concerning how well the river trip fulfilled the respondent's expectations, measured on a 6-point (terrible to excellent) response format; and (3) situational variables. The selection of these potential independent variables as indicators of satisfaction follows the discrepancy theory approach outlined earlier. The various response formats also provide some response diversity that may be useful in explaining overall satisfaction. The stepwise regression identified elements of the river trip that contributed to overall satisfaction and the extent to which overall satisfaction could be explained.

FINDINGS AND DISCUSSION

Responses to the five statements representing overall satisfaction are shown in table 1. These statements are in essence different ways of measuring the extent of satisfaction with the river trip as a whole. Notice that items 4 and 5 are negatively worded (i.e., disagreement with the statements indicates higher satisfaction). Such item reversals were intended to avoid response sets. All but one of the five items received response patterns indicating high trip satisfaction and thus repeating the findings in previous studies. Item 2, on the other hand, received a more neutral response with an even extent of agreement and disagreement. This is not surprising because item 2 posed a more demanding satisfaction question by asking respondents to compare their trip to the best trip they could imagine. The item means suggest that the five items represent the neutral to high range of the overall satisfaction continuum.

Reliability statistics (item-total correlations and Cronbach alpha) calculated for the summated rating scale comprised by these five items are also given in table 1. Together the five statements produced the best measure of overall satisfaction available from any subset of the five items. Deleting any single item from the scale would lower the remaining scale's standardized alpha. Item 2 is the weakest member of the scale as seen by its low item-total correlation coefficient and the smallest reduction in alpha if it was deleted from the scale. However, item 2 was retained in the scale because of its contribution to scale reliability and because it was the only scale item that sampled the neutral range of the satisfaction domain.

Stepwise regression analysis was then used to determine the importance of each element in explaining the variance in overall satisfaction—the overall satisfaction scale was the dependent variable and selected situation variables, trip fulfillment scores, and specific satisfaction statements were independent variables (table 2). Nine items accounted for 39 percent of the variance in overall satisfaction. About 20 percent of the variability was attributable to the level of agreement with the statement, "I was very pleased with the scenery". To what degree the float trip was able to fulfill the "opportunity to have thrills and excitement" explained another 8 percent of the variance. The level of agreement with the statement "I was pleased by the job being done by managers of the river" accounted for another 4 percent of the variance.

Table 1.—*Overall satisfaction scale item composition*

Scale item	Frequency of responses (percent)					N	Item mean	Standard deviation	Corrected item—total correlation	Alpha[1] if item deleted
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree					
1. I thoroughly enjoyed the trip	1	2	3	50	44	798	4.35	0.6689	0.4521	0.6385
2. I cannot imagine a better river trip	6	27	32	26	9	789	3.02	1.0583	0.3889	0.6679
3. The river trip was well worth the money I spent to take it	1	3	9	60	27	787	4.11	0.7112	0.4722	0.6286
4. I do not want to run any more rivers like this one	41	47	8	3	1	788	1.77	0.7916	0.4615	0.6278
5. I was disappointed with some aspects of my trip	22	37	19	20	2	785	2.42	1.0876	0.4981	0.6119

[1] Alpha = 0.7041

Table 2.—*Results of regression of selected independent variables on the overall satisfaction scale*

Independent variable	B	Standard error B	F	Cumulative R^2
I was very pleased with the scenery	0.2511	0.0314	64.08	0.2051
Opportunity to have thrills and excitement	0.1062	0.0178	35.75	0.2893
I was pleased by the job being done by managers of the river	0.1151	0.0243	22.52	0.3275
Opportunity to get away from the usual demands of life	0.1086	0.0224	23.54	0.3476
The number of people I saw on the river bothered me	0.0903	0.0203	19.75	0.3614
I wish there had been more rapids	0.0762	0.0205	13.83	0.3728
The river went through some very wild country	0.0459	0.0173	7.04	0.3786
About how many canoes passed you on the river today	0.0023	0.0010	5.75	0.3831
I thought the river and its surroundings were in good condition	0.0610	0.0277	4.85	0.3875
(Constant)	(0.5365)			

Tables 3 through 7 present the results of similar regression analyses conducted with each of the individual satisfaction scale items as the dependent variable. None of the coefficients of determination (R^2) for the five single items approached the 0.39 R^2 of the overall scale. However, items 1 and 3 achieved an R^2 of 0.30 and 0.33, respectively. In addition, no consistent order was found of variable entry into the regression equations across all five items and the overall scale. This is an important point because if the overall satisfaction indicators all measured the same thing, the same variables, in roughly the same order, would occur in each regression analysis.

Items 1 and 3 and the overall scale shared several of their first five variables. Most noteworthy was the large contribution the scenery variable made to the total R^2 value of each of the three regressions. In each case, this variable accounted for more than half of the variance. From an intuitive standpoint the similarities in extent of explanation and selection of variables between the overall scale and items 1 and 3 make sense. A response to either of these two single items does not ask the respondent to compare his float trip to some ideal trip as in item 2 or to compartmentalize different aspects of his trip as in item 5. Both relate to the overall trip in general. Hence, the same variables are found to explain most of the variance in each of these items and the overall scale, and the amount of variance accounted for by items 1 and 3 is the highest for any single item indicator.

Examining the regressions on satisfaction items 2, 4, and 5 leads to several observations. First, when satisfaction is measured by comparing the present river trip to some hypothetical "better trip" as in item 2 (table 4), different variables become important in explaining variability. The opportunity to have thrills and excitement was found to be the most important indicator of how closely the actual trip approached the ideal trip. Entry of the variable, "I wish there had been more rapids," at the third step futher supported the role of challenging water conditions in the image of the ideal river trip.

Similarly, satisfaction item 5, which required respondents to think in terms of the various aspects of their trip, was best explained by a still different array of independent variables (table 7). In this case, the number of people encountered on the river was an important independent variable. Notable in this regression was the small amount of total variance accounted for and the small R^2 attributable to the first variable to enter the equation.

Satisfaction item 4 incorporated a hypothetical behavioral dimension to overall satisfaction with its reference to future river trips (table 6). The selection of independent variables showed no unique departures from the pattern established by the overall scale and items 1 and 3, but the coefficient of determination was much lower ($R^2 = 0.13$).

Table 3.—*Results of regression of selected independent variables on scale item 1: I thoroughly enjoyed the trip*

Independent variable	**B**	**Standard error B**	**F**	**Cumulative R^2**
I was very pleased with the scenery	0.2948	0.0372	62.75	0.1822
Opportunity to have thrills and excitement	0.1238	0.0221	31.37	0.2540
Opportunity to get away from the usual demands of life	0.1075	0.0275	15.32	0.2702
I was pleased by the job being done by managers of the river	0.1018	0.0286	12.62	0.2846
How did the number of people you saw today affect the overall enjoyment of your float trip	0.0589	0.0183	10.39	0.2952
(Constant)	(1.4410)			

Table 4.—*Results of regression of selected independent variables on scale item 2: I cannot imagine a better river trip*

Independent variable	B	Standard error B	F	Cumulative R^2
Opportunity to have thrills and excitement	0.2382	0.0378	39.70	0.1322
I was pleased by the job being done by managers of the river	0.1093	0.0482	5.15	0.1604
I wish there had been more rapids	0.2214	0.0406	29.71	0.1868
The river went through some very wild country	0.1501	0.0336	19.90	0.2082
The people I saw on the river did not bother me	0.1428	0.0443	10.40	0.2238
About how many canoes passed you on the river today	0.0110	0.0026	17.54	0.2366
I was very pleased with the scenery	0.1507	0.0609	6.12	0.2442
Opportunity to share what I have learned with others	0.1215	0.0395	9.45	0.2504
About how many canoes on the bank and in the water did you pass on the river today	–0.0044	0.0020	5.02	0.2559
I thought the river and its surroundings were in good condition	0.1157	0.0565	4.19	0.2608
Opportunity to be a part of a group	–0.0707	0.0366	3.74	0.2649
(Constant)	(–1.0600)			

Table 5.—*Results of regression of selected independent variables on scale item 3: The river trip was well worth the money I spent to take it*

Independent variable	B	Standard error B	F	Cumulative R^2
I was very pleased with the scenery	0.3959	0.0384	106.20	0.2473
To get away from the usual demands of life	0.1410	0.0271	27.04	0.2815
I was pleased by the job being done by managers of the river	0.1342	0.0301	19.91	0.3113
The river went through some very wild country	0.0648	0.0213	9.23	0.3195
How did the number of people you saw today affect the overall enjoyment of your float trip	0.0415	0.0182	5.20	0.3251
I thought the river and its surroundings were in good condition	0.0675	0.0346	3.81	0.3288
(Constant)	(0.5802)			

Table 6.—*Results of regression of selected independent variables on scale item 4: I do not want to run any more rivers like this one*

Independent variable	B	Standard error B	F	Cumulative R^2
I was very pleased with the scenery	0.2955	0.0481	37.79	0.0930
Opportunity to get away from the usual demands of life	0.1383	0.0345	16.10	0.1141
I thought the river and its surroundings were in good condition	0.1225	0.0448	7.47	0.1192
The people I saw on the river did not bother me	–0.1259	0.0391	10.40	0.1254
The number of people I saw on the river bothered me	0.0937	0.0345	7.38	0.1347
(Constant)	(1.9672)			

Table 7.—*Results of regression of selected independent variables on scale item 5: I was disappointed with some aspects of my trip*

Independent variable	B	Standard error B	F	Cumulative R^2
The number of people I saw on the river bothered me	0.1938	0.0461	17.68	0.0558
I was pleased by the job being done by managers of the river	0.1962	0.0506	15.05	0.0935
Opportunity to have thrills and excitement	0.0826	0.0389	4.52	0.1169
I wish there had been more rapids	0.1943	0.0440	19.53	0.1334
I was very pleased with the scenery	0.2072	0.0659	9.90	0.1501
Opportunity to get away from the usual demands of life	0.1402	0.0481	8.49	0.1583
The rivers went through some true wilderness	–0.1032	0.0404	6.53	0.1664
About how many canoes on the bank and in the water did you pass on the river today	0.0032	0.0015	4.37	0.1718
How did the number of people you saw today affect the overall enjoyment of your float trip?	0.0701	0.0345	4.12	0.1768
(Constant)	(–0.0957)			

IMPLICATIONS

If the overall satisfaction scale is an improved measure of satisfaction and the theoretical reasoning behind the independent variables is valid, one would expect a better predictive model for the satisfaction scale than for single satisfaction indicators. The lower coefficients of determination obtained for individual items would then be largely a function of the unique item variance associated with the individual items.

This explanation of the findings of this study leads to some practical implications for interpreting past satisfaction studies and designing future ones. The greatest inconsistencies in the predictive models for the various dependent variables were found for those that were most "innovative," or most divergent in question wording from typical questions assessing overall satisfaction. Relating this to the earlier discussion of psychological responses associated with satisfaction (Schreyer 1979) reinforces the idea that overall satisfaction is complex, nebulous, and fluid to recreationists. When questions provide greater detail or structure concerning what is meant by satisfaction, as in questions introducing an ideal trip (item 2) or an expectation to repeat the type of trip (item 4) or the idea of thinking of the trip in terms of its aspects (item 5), specific unexpected reactions were evoked. The best predictors for overall satisfaction were no longer the best predictors for some of these indicators.

Instead of muddying the waters, this finding introduces some new possibilities. The use of such innovative satisfaction statements is advantageous because it represents different subdimensions and different levels of feeling about satisfaction. Although the lowest R^2 values were found for the more innovative dependent variables, it should be recognized that these are the types of variables that tap the previously unexplored ranges of the satisfaction continuum. Inclusion of these statements in the satisfaction scale resulted in the best predictive model available, suggesting that the items collectively provided the most comprehensive and realistic measure of overall satisfaction.

Implications of these findings for measuring satisfaction in future studies depend in large part on how satisfaction is to be conceived. If satisfaction is conceptualized as a general disposition, using a measurement scale is clearly advantageous over using single item indicators. Increased experimenting with these and other scale items can lead to improvements in both scale reliability and range. Devoting greater attention to the development of innovative satisfaction indicators will be especially helpful in sampling the domain of overall satisfaction. In addition to their scale contribution, new scale items may less ambiguously describe particular subdimensions of overall satisfaction.

Use of this overall satisfaction scaling approach is not dependent upon nor mutually exclusive of determining the multiple components of total satisfaction in a given situation. The regression analyses reported here support the theory that overall satisfaction is influenced by satisfaction with specific aspects of the experience. However, the observed extent of explanation of the variance ($R^2 = 0.39$) leaves room for improvement in the model. Studies concerned with identifying the variables that contribute to understanding satisfaction would benefit from increased attention to the development of potential independent variables. Additional improvements in the model might also be obtained through further data analysis. For example, the models presented reflect the full heterogeneity existing in the study population. They are, in effect, averages. Recognizing that satisfaction means different things to different people, we might hypothesize that explanation of satisfaction can be enhanced by identifying and formulating separate predictive models for more homogeneous groups of river floaters.

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ATTRACTION OF RECREATIONISTS TO RIVERS: A NATIONWIDE VIEW

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INFORMATION NEEDED BY RIVER MANAGERS

River recreation has grown remarkably in this country in recent years and has become a major American outdoor activity (USDA Forest Service 1977). Unless energy costs and shortages and economic malaise create major disruptions, the trends are likely to continue. Unfortunately, for the growing number of enthusiasts in search of free-flowing streams and backcountry solitude, the supply is limited.

Most of the really desirable rivers run through public land. In most of those locations the demand for services and facilities and the impacts of recreational use have grown to the point that the rivers and their users now must be managed to ensure safety and sanitary conditions, to ameliorate conflict, and to prevent the quality of the resource from being damaged unacceptably. When navigable rivers pass through private land, government intervention is often required and justified for the same reasons.

The people who have the job of managing rivers for recreation have a great need for information. Specifically, they need answers to the following questions:

- What is the potential demand for different uses of a river?
- How important or valuable is a river for various kinds of use?
- What are the trends in use, particularly with respect to energy or economy-related changes in willingness to pay and willingness to travel?
- What are the social and personal benefits of river recreation?
- Is a given river a resource of local, regional, or national significance? Do local users come to the river for different reasons than people who travel greater distances? Is the river more or less important to them?
- How unique is the river? Is it a scarce resource or simply one of many? What are the competing alternatives?
- How efficient is the river's location vis-a-vis potential users? Are more efficient alternatives available that might be encouraged?
- What are the specific characteristics of the river that attract its users? What are the purposes or motives that draw people to the river?
- How sensitive are different types of users to conditions of the resource and to management actions?
- What are the impacts on the public of rationing and allocation schemes? How are those impacts distributed geographically and socially? Who benefits and who loses economically when allocation and rationing schemes are imposed? Do those schemes create the opportunity for abnormal profits for commercial users?
- Where does a particular river fit in a nationwide system of recreation opportunities?

The purpose of this paper is to show how methods of travel demand analysis can be used to help provide answers to these questions.

THE INFORMATION CONTAINED IN TRAVEL CHOICES

When stripped of their situational idiosyncrasies, most of the questions raised above boil down to the following:

1. What choices will people make under various circumstances?
2. What will change as a result of those choices?
3. What variables in the process can and should be controlled by the manager?

River recreation management is largely a matter of predicting behavior, predicting the impacts of behavior, and designing and implementing interventions to modify behavior and/or its impacts (Peterson and Lime 1979).

Much research has been devoted to these problems, many different methods have been used, and much useful information has been generated. However, we feel that there has been little theoretical reasoning and not enough scientific observation of real choices. No one yet has figured out how to get atoms and molecules to fill out questionnaires, but the sciences of chemistry and physics have made good progress in spite of this.

Much can be learned from the recreational travel choices that people make. Travel is generated by a decision process that has been explained and modeled in a variety of ways in the transportation demand literature (Stopher and Meyburg 1975). Except when the travel itself is the object of recreation, the decision process can be simplified as a tradeoff between the attractiveness of alternative destinations and the cost of the travel. This assumes that a decision has been made already to engage in a recreational activity that creates a need for the kind of services and resources available at alternative destinations.

Several factors are involved in the site choice:
(1) The importance or value of the activity one wants to engage in, e.g., skiing, fishing, canoeing, etc.[1]

(2) The quality of the facilities, resources, and services available at alternative locations.

(3) The impedance or travel cost separating the individual from each of the possible destinations. Personal variables such as age, sex, personality, past experience, occupation, and income, will influence the value one places on the activity. Site characteristics and personal variables will modify the perceived quality of the site for that activity. Distance, mode of travel, and personal variables will modify the magnitude of the travel impedance. Thus, careful observation and analysis of travel choices can reveal information about the person, the activity, the site, and the impedance. A framework of theory and method is required, however, if the intricately interwoven effects are to be isolated. Two approaches are considered here: site attractiveness modeling and site choice modeling.

SITE ATTRACTIVENESS MODELING

Site attractiveness modeling looks at the ability of a site to attract visitors from the surrounding area. It attempts to explain the number of visitors attracted from various areas in terms of (a) characteristics of the site, (b) the purpose of the visit, (c) the distance traveled, (d) the population density and other demographic variables at the trip origin, (e) personal characteristics of the visitors, and (f) the supply of competing opportunities. The key point in site attractiveness modeling is that the analysis is done from the point of view of a specific site in order to understand its relation to the market and the process by which it attracts its visitors.

In its simplest form such analysis might begin with assumptions such as (1) the site has no competitors, (2) all visits are for the same single purpose, (3) the population at any specific trip origin is homogeneous with respect to personal and demographic variables to which the recreational travel decision might be sensitive, and (4) all areas in which trips originate are identical except for population density and distance from the site. Of course, such assumptions will never be true, but they provide a background for a simple illustrative model.

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[1] *If the object of the paper were to develop a theory of recreational choice, we would want to back up several steps and deal with situational variables and with needs, motives, and expected outcomes before moving to activity choice (Peterson et al. 1978). We would also want to explore the sequence in which various decisions occur. However, for the sake of simplicity it is assumed that the process begins with activity choice and then goes to site choice.*

Let the area from which potential visitors to a river are attracted be divided into a set of discrete zones, $i = 1,2,\ldots,n$, and define

V_i = the number of visits observed from zone i

Z_i = the total population of zone i

$\sum_{i=1}^{n} V_i$ = the total number of visitors observed at the site from all zones, and

D_i = the distance from zone i to the site.[2]

If the V_i are sampled randomly and represent the distribution of visits from all zones, then

$$\{ \frac{V_i}{\Sigma V_i} \} = p(i), \tag{1}$$

where p(i), is the probability that a randomly observed visit at the site is from zone i. If the population of zone i is homogeneous, the conditional probability that a visit is person k from zone i, given that the visit is from zone i, is

$$p(k/i) = \frac{1}{Z_i} . \tag{2}$$

If the population is not homogeneous,

$$\varepsilon \{p(k/i)\} = \frac{1}{Z_i} . \tag{3}$$

Given homogeneity at the origin, the probability that a visitor is person k from zone i is

$$p(ki) = p(i) \circ p(k/i) \tag{4}$$

$$= \varepsilon \{ \frac{V_i}{Z_i \Sigma V_i} \}. \tag{5}$$

The object of the analysis is to explain p(ki), as given by Eq. (5), as a function of the impedance (distance, travel time, travel cost, etc.) between the zone and the site. A simple plausible form for the relation is

$$p(ki) = \varepsilon \{ \frac{V_i}{Z_i \Sigma V_i} \} \simeq \alpha \; D_i^{-\beta} . \tag{6}$$

To preserve the properties of probability the following must be true:

$$\sum_{i=1}^{n} \sum_{k=1}^{Z_i} \alpha \; D_i^{-\beta} = 1, \tag{7}$$

which implies

$$\alpha = \frac{1}{\sum_{i=1}^{n} Z_i D_i^{-\beta}} \tag{8}$$

and the complete function becomes

$$p(ki) = \varepsilon \{ \frac{V_i}{Z_i \Sigma V_i} \} \simeq \frac{D_i^{-\beta}}{\sum_{i=1}^{n} Z_i D_i^{-\beta}} ; \text{ or} \tag{9}$$

$$p(i) = \varepsilon \{ \frac{V_i}{\Sigma_i V_i} \} \simeq \frac{Z_i \; D_i^{-\beta}}{\sum_{i=1}^{n} Z_i D_i^{-\beta}} . \tag{9a}$$

In Eq. (6), the exponent is the distance elasticity of p(ki) in the presence of the existing supply of competing opportunities. It can be estimated in Eq. (9) by maximum likelihood methods. However, a reasonable approximation can usually be obtained for from Eq. (6) using ordinary least squares regression.

In practical applications, the simple models given by Eqs. such as (6) and (9) are generally able to explain a significant portion of the variance in the number of visitors arriving from different zones. However, the assumptions of intra- and interzone homogeneity are unrealistic. Within a zone, individuals may vary with regard to their likelihood of visiting the river. This variance can be explained, in part, by measurable personal variables. It is also likely that significant differences will exist among zones in addition to differences in distance and size to population. Some of those differences may be social, economic, or cultural in nature while others may stem from the locations of intervening opportunities. In short, it is possible to substantially improve the model by specifying it in terms of more variables that describe interpersonal and interzonal variables.

Disaggregate formulation of the model with the individual trip as the observation (rather than the aggregate zone) allows the further inclusion of differences in perception and importance of site attributes. Of course, the model given in Eqs. (6) and (8) makes some demanding assumptions and is only one of several possibilities. It should be evaluated thoughtfully in any given application.

Other things being equal, the exponent β will vary with:

(1) the importance of the activity for which the site is used,

(2) the attractiveness or "quality" of the site for the activity in question,

(3) the cost or "price" of distance, and

(4) the quality and location of competing sites, should the assumption be untrue.

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[2] *For a specific application it may be advantageous to define this as travel time or actual travel cost or to stratify it by travel mode.*

The coefficient in Eq. (7) varies with β and with the locational efficiency of the site. Given a fixed value of β for a particular activity, site, and type of person, then $1/\Sigma Z_i D_i^{-\beta}$ measures differences in locational efficiency.

Much useful information can be generated with cautious application of this type of site-specific analysis. One such application is the estimation of trip "demand" functions to evaluate willingness to pay for a site (Dwyer *et al.* 1977). Another is to compare the value of a site for several different activities for which it might be used (recognizing that differences in the value of the site may reflect differences in supply conditions and distribution of client populations as well as differences in site characteristics).

Changes in the cost of travel and in the willingness to travel would be reflected in changes in β. Related to the uniqueness of a site is the question of whether it is important locally, regionally, or nationally. This can be examined quantitatively by means of site attractiveness modeling. Differences in the meaning of a site to different segments of the population can also be exposed. It must be recognized, however, that this kind of model is heuristic and empirical. It describes the trip-attraction of a site, but "demand" interpretation should be done cautiously for reasons discussed in a later section.

The following two subsections illustrate application of site attractiveness modeling. The first is a hypothetical exploration of the impacts of site rationing. The second is an empirical description of several rivers studied in 1977 as part of the National River Recreation Study.

An Illustrative Theoretical Application: The Impact of Rationing

One important problem to which attractiveness modeling can be applied is the impact of rationing. Assume that a daily carrying capacity has been defined for a given whitewater river and that demand greatly exceeds supply. A lottery is therefore established to assign available "trip-days" among applicants. Assume the lottery ratio is 1:2 (for every two applications only one permit can be granted).

A crucial question is whether the willingness to submit an application is the same as the willingness to travel to the river. It seems reasonable to assume there might be a greater propensity to submit an application in anticipation of a possible trip than to travel to the river if a permit is granted. In other words, "β" for the application process might be different than "β " for the actual travel process.

In figure 1, Curve A is a hypothetical applicant function, with the number of applicants per capita on the vertical axis and the distance to the site on the horizontal axis. Curve B is then the number of permits granted per capita as a function of distance at the 1:2 lottery ratio. Let Curve C be the actual number of visits per capita that would arrive from various distances without rationing. The relation between Curve A and Curve C implies the distance elasticity of applications is less than the distance elasticity of travel to the site. In general, more people apply than are willing to travel.

If this assumption is correct, then:

1. The "no-show" rate may tend to increase with distance from the site.

2. The likelihood of being denied a permit may increase with decreasing distance. In other words, local users may be discriminated against. A possible interpretation of this, based on economic theory, is that higher valued and more specialized uses may tend to be favored and a higher percentage of lower-valued uses may tend to be denied. This would be an implied policy redefining the "purpose" of the resource.

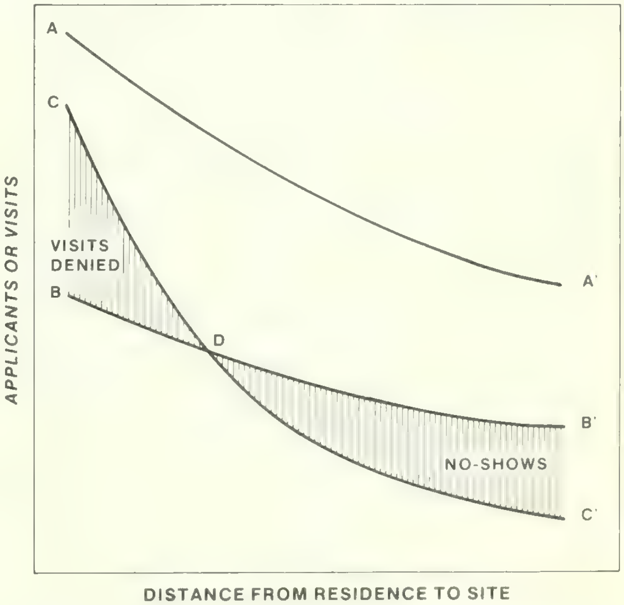

Figure 1.—*Potential geographic impacts of lottery rationing.*

3. Actual use resulting from the rationing system may fall below the permitted capacity because permits assigned to people unwilling to travel will go unused. Thus, it may be desirable to increase the lottery ratio until the actual use rate achieves capacity.

4. It may be desirable to formalize a "hovering" policy whereby people are encouraged to obtain "no-show" permits at the site on a first-come-first-served basis. This substitutes "willingness to wait and take risk" for "willingness to travel" and tends to redistribute "no-show" permits to local users.

5. It may be desirable to consider an application fee or deposit that is forfeited if a permit is not used. This would modify the elasticity of the application process (Curve A in fig. 1) and perhaps bring it more in line with the actual travel process (Curve C).

The distributional impacts hypothesized above may or may not be desirable. However, if the rationing system is designed on an *ad hoc* basis at the local level without explicit analysis of these issues, there may be implied *policy* that ought to have been resolved politically or perhaps administratively at more general levels in the agency.

Attractiveness modeling offers a tool for explicit analysis of these questions. Analysis of application, permit, and actual trip data can reveal the size of the "no-show" population, how far people are willing to travel, etc.

The possibility of secondary impacts of lottery rationing is suggested by this kind of analysis. Assume the river has no substitutes. Limiting supply through lottery rationing may create unsatisfied demand so people may be willing to pay more than the required travel cost. If use is also allocated between the private sector and the commercial operators who outfit and guide river trips, the people who applied for private trips but were turned away by the lottery would have the option of purchasing the services of a commercial operator. Many of these people may be willing to pay more than their travel cost and the normal cost of services and equipment. If the commercial capacity is reached, as with some western whitewater rivers, the unsatisfied private demand might begin to bid up prices beyond a normal charge for services. In effect, this would be a transfer of consumers' surplus from the private sector to abnormal profits in the commercial sector.

It is not our purpose to imply such impacts of river resources rationing are occurring or to predict that they will occur in the future. Rather, rationing is an example of river management action that is taking place in an ad hoc fashion, perhaps without explicit knowledge of all the impacts. Information about the processes by which applications and trips are generated can help clarify the impacts through attractiveness modeling. The potential impacts described above are illustrative of what might happen, given some assumptions about demand.

An Illustrative Empirical Comparison of Several Rivers

Since the summer of 1977 the National River Recreation Study has been collecting data about the recreational use of numerous rivers. The data include information on the points of origin of trips to the river as well as other descriptive details about visits. Trip-origin data have been used in a preliminary "site attractiveness" analysis of 12 rivers: Mohican (Ohio), Hiwassee (Tennessee), Ocoee (Tennessee), Deschutes (Oregon), Apple (Wisconsin), Illinois (Oklahoma), Nantahala (N. Carolina), Upper Colorado (Colorado), Upper Missouri (Montana), Main Salmon (Idaho), the Middle Fork of the Salmon (Idaho), and the Chattooga (S. Carolina/Georgia) (table 1).

Results displayed in table 1 should be regarded as illustrative. They were obtained by ordinary least squares regression estimates of the logform of Eq. (6). Work in progress is exploring complete estimation of Eq. (9) by maximum likelihood methods for a larger set of rivers (including rivers studied in 1978 and 1979).

Strong differences exist among the 12 rivers with regard to β , average distance traveled, and average distance from the people.[3] The Main Salmon and the Middle Fork show the least sensitivity to distance and tend to attract visitors from much farther away. These were the only rivers in the study under permit rationing at the time the data were collected. Geographical shifts in trip origins would tend to produce the kinds of differences observed in β and average distance traveled. However, these rivers also are a different kind of resource than most of the others in that they are "wilderness" whitewater rivers requiring about 5 days to float. With the exception of the Missouri River, which is a long multiple-day flat water river, the rivers are generally used for day-trips. The required trip length would tend to make

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[3] *The average distance traveled if every person in the country made one trip to the river. This is not the distance from the population centroid.*

Table 1.—*Preliminary Estimation of "β" for 12 Rivers*

River	– "β"[1]	Average distance[2] traveled	Average distance[3] from the people	Observations	R^2[4]
		—Miles—		No.	
Mohican	–2.64	76	722	444	0.84
Hiwassee	–2.87	94	771	128	0.86
Ocoee	–2.61	97	769	280	0.88
Chattooga	–2.26	156	787	9,877	0.73
Deschutes	–2.48	164	1,743	456	0.80
Apple	–2.03	166	880	191	0.75
Illinois	–2.27	166	856	226	0.79
Nantahala	–2.08	259	770	87	0.70
Colorado	–2.02	266	1,177	2,169	0.80
Missouri	–3.03	268	1,416	497	0.91
Main Salmon	–1.78	822	1,591	175	0.74
Middle Fork	–1.81	873	1,508	191	0.70

[1] As estimated by least squares in the log form of Eq. (6).

[2] Based on one-way airline distance between points.

[3] The average distance travelled if every person in the country made one trip to the river.

[4] Fraction of the variance among zones explained by the estimate of Eq. (6).

the Main Salmon, Middle Fork, and Missouri Rivers more the object of major vacations; and, this also would tend to produce the kinds of differences observed in β and average distance traveled.

When data become available on a large number of rivers nationwide, it may eventually be possible to explain differences in β and average distance traveled in terms of such variables as (1) characteristics of river and river setting, (2) river location, (3) type of use, (4) duration of visit, (5) management policy (e.g., rationing), and (6) intervening opportunities. It also is likely that Eq. (6) is under-specified, and adding more variables might improve explanation. For example, the geographic distribution of prediction errors for the Upper Colorado River clearly shows that they are not randomly distributed about the country (fig. 2). This implies possible effects of other variables such as geographically selective marketing strategies, demographic and/or cultural differences, and competing opportunities.

SITE CHOICE MODELING

Attractiveness modeling produces useful information for a specific river; but, in the simple form presented above, it cannot evaluate the role of that river in the process that allocates demand among all rivers nationwide. Site choice modeling is a way to look at the allocation of demand to a specific river in the context of a national system of rivers.

To illustrate the concept by means of an aggregate model, assume the nation can be divided into geographic zones. Each zone i delivers V_{ij} visits to river j.

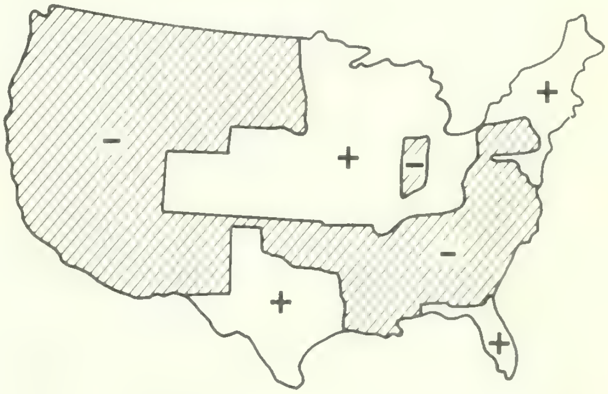

Figure 2.—*Geographic distribution of prediction errors for the Upper Colorado River in central Colorado.*

⊞ = *portions of the country that generate more trips than the model predicts and*

⊟ = *portions of the country that generate fewer trips than the model predicts.*

Let the rivers in the set containing j be substitutes and exhaustive of all rivers in the nation of that type. Now define

$P_i(j/i)$ = The probability that a person in zone i will choose destination j.

Site choice modeling attempts to explain this probability in terms of (a) variables describing the persons and/or zones, (b) variables such as distance describing the relation of the persons and zones to the rivers, and (c) attributes describing the rivers (such as physical, biological, and social conditions).

The approach generally used for site choice modeling is multinomial logit analysis, which may be formulated as follows:

$$P_i(j/i) = \frac{e^{U(D_{ij}, X_j, d_j)}}{\Sigma_k e^{U(D_{ik}, X_k, d_k)}} \qquad (10)$$

where $U(D_{ij},X_j,d_j)$ is the utility function describing the value or utility of river j,

D_{ij} is a vector of variables describing travel impedance from i to j (such as distance, travel time, travel cost),

X_j is a vector of attributes describing the rivers, and

d_j is a set of destination-specific dummy variables that capture specification and sampling errors.

Eq. (10) is an aggregate formulation if the population of zone i is homogeneous. In this model the zone is the observation. Socioeconomic differences among individuals and/or zones would be captured as interaction variables by population segmentation. The model also has a disaggregate form in which the individual would be the observation.

The primary purpose for including this material on site-choice modeling is to help put the attractiveness model discussed earlier in its proper context. However, the site-choice or trip distribution problem is interesting by itself. Work in progress is using National River Recreation Study data from 1977, 1978, and 1979 to test and estimate a specific form of Eq. (10). This kind of analysis contributes to an ability to predict demand and estimate benefits for a given river in the context of a larger system of river opportunities. The sensitivity of demand to factors such as energy cost can be evaluated and trends over times can be observed.

LIMITATIONS OF EMPIRICAL SITE ATTRACTIVENESS MODELING

The site-choice model is a "trip-distribution" model that allocates trips among alternative destinations, given trip demand at the origins. The logit model (Eq. 10) is derived by the criterion of utility maximization, given the utility function and certain assumptions about the process. Thus, it can be regarded as a demand function from which demand distribution elasticities can be calculated for the variables in the utility function.

Such a site-choice model does not deal with the amount of demand generated, however. The problem is clarified by deriving a site-attractiveness model for a single site, in the presence of many sites, from the site choice model. For simplicity, let the trip-distribution component of the utility function be U_1 with the understanding that it contains the relevant variables to which utility is sensitive in site choice. Let the site-choice probability be p(j/i), the probability that a trip originating at origin i will choose destination j. Let the site-attractiveness probability be p(i/j), the probability that a trip observed at destination j originates at origin i.

Given the assumption of logit theory, the utility-maximizing site choice model is

$$p(j/i) = \frac{e^{U_1}}{\Sigma_j e^{U_1}} . \qquad (11)$$

The number of trips from i to j is

$$V_{ij} = p(j/i)\Sigma_j V_{ij} = \frac{e^{U_1}}{\Sigma_j e^{U_1}} \Sigma_j V_{ij}, \qquad (12)$$

where $\Sigma_j V_{ij}$ is the total number of trips generated at origin i.

Assume that trip generation can be described as a function of U_2, the trip generation component of the utility function:

$$V_{ij} = \frac{e^{U_1}}{\Sigma_j e^{U_1}} f_i(U_2) . \qquad (13)$$

Eq. (13) is a site-demand function. The general site attractiveness model is

$$p(i/j) = \frac{V_{ij}}{\Sigma_i V_{ij}} = \frac{\dfrac{e^{U_1}}{\Sigma_j e^{U_1}} f_i(U_2)}{\Sigma_i \{\dfrac{e^{U_1}}{\Sigma_j e^{U_i}} f_i(U_2)\}} . \qquad (14)$$

If U_1 and U_2 are separable and independent components of the consumer utility, trip generation and trip distribution can be analyzed as independent demand processes.

Eq. (13) is the form of a model proposed by Cesario and Knetsch (1976). Their model can be expressed as

$$V_{ij} = \{\frac{A_i^{b_2} \exp(b_3 C_{ij})}{\Sigma_k A_k^{b_2} \exp(b_3 C_{ik})}\} b_o P_i^{b_1} \{\Sigma_k A_k^{b_2} \exp(b_3 C_{ik})\}^{b_4 + 1}$$

where P_i = population or origin i,
A_j = attractiveness of destination j,
C_{ij} = generalized travel cost from i to j, and
$b_o \ldots b_4$ = estimated parameters.

For utility maximization, their distribution function implies

$$U_1 = b_3 C_{ij} + \ell n A_j^{b_2} . \qquad (16)$$

The trip generation portion of the model is a function of the logit function denominator, which is a generalized measure of utility, vis-a-vis each origin, in terms of the quality of all sites and the accessibility of the origin to those sites.

Although the trip generation portion of the Cesario and Knetsch model is apparently an empirical form and not a utility-maximizing demand function, it implies, as we would intuitively expect, that U_2 is sensitive to the variables in U_1. This further implies that generation and distribution of demand are not independent, although U_1 and U_2 may be separable.

The following conclusions are important:

1. When the site being analyzed has no substitutes, the trip distribution function degenerates to unity and the site demand function is the trip generation function.

$$V_{ij} = f_i(U_2) \qquad (17)$$

and

$$V_j = \Sigma_i f_i(U_2) . \qquad (18)$$

In such a case, the site attractiveness function is

$$P(i/j) = P(i) = \frac{f_i(U_2)}{\Sigma_i f_i(U_2)} . \qquad (19)$$

This is the form of Eq. (9a), a version of the illustrative simple attractiveness model described earlier, in which it is implied that

$$f_i(U_2) \simeq g(x) Z_i D_i^{-\beta} , \qquad (20)$$

where g(x) is some function of the attributes of the site. Note that g(x) factors out and disappears in Eq. (9), (9a), and (20) and therefore is irrelevant in those equations. If Eq. (20) is a correct specification and Eq. (9) is estimated by unbiased methods, β can be compared between different sites that do not have competitors. It provides information about the sensitivity of attractiveness to distance.

2. When competing sites are present but U_1 contains no origin-conditional information, the trip-distribution function factors out of Eq. (15). The site attractiveness function again simplifies to Eq. (20). However, trip generation may be a function of total supply (the denominator of the distribution function), as in the Cesario-Knetsch model. If so, complete knowledge of the attributes of competing sites still is required.

3. When U_1 contains origin-conditional information (such as distance) and competing sites exist, the more general Eq. (15) should be used for complete site attractiveness analysis. In this case the analysis of a specific site requires knowledge of the relevant attributes of *all* competing sites and the trip generation function for all origins in the presence of all competing sites.

4. When competing sites are present and trip distribution is sensitive to origin-conditional variables such as distance, a model like Eq. (9) is a heuristic description of an empirical relation between trip attraction and distance (and/or other variables that might be included). It can be regarded as a conditional site attractiveness function. It is conditional on other variables being held constant, such as the location and attributes of the site in question and the location, number, and attributes of competing sites. Therefore, it is *not* generalizable from one site to another. It describes only the site in question under the conditions prevailing when the data were collected. Still, information thus presented is useful to the managers of that site if the limitations are understood.

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USER PERCEPTIONS OF RIVER RECREATION ALLOCATION TECHNIQUES

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Recreational use limits of some kind have been implemented on about 45 river segments in the United States (McCool 1978, McCool *et al.* 1977). Although most river floaters accept the necessity of such limits (Roggenbuck and Schreyer 1977), the question of how to allocate limited use opportunities remains a controversial one. Historically, river managers have employed allocation policies that differentiate between commercial users (who pay outfitters to provide boats, guides, food, and equipment necessary for a float trip) and private users (who float a river with their own equipment and expertise). The principal question associated with such policies is: "How should use be divided between these two sectors?" A subsequent management problem centers around the issue of how to distribute use opportunities within the private sector. Past management decisions concerning these questions have been subject to a substantial number of threatened and actual lawsuits, civil disobedience, and Congressional inquiry (Utter and McCool 1978).

The use allocation issue on whitewater rivers is comprised of two subissues that we have termed **allotment** and **rationing**. Following a decision to handle the commercial and private sectors separately, a management agency must determine how much use to apportion or **allot** to each sector. Next, distribution of individual use opportunities, or **rationing**, occurs. The agency rations use opportunities in the private sector by employing some form of nonmarket mechanism such as first-come first-served, or a permit lottery (Stankey and Baden 1977). Individual use opportunities within the commercial sector, however, usually are not rationed by the agency; rather, outfitters ration commercial use through a type of pricing system (over which agencies exercise varying degrees of control) in which they sell river trips to people willing and able to pay for them.

The purpose of this paper is to examine selected results from a study of use allocation on the Middle Fork of the Salmon River in Idaho. Two main topics are discussed. The first deals with the preferences of actual and potential river users for various allotment and rationing techniques. The second deals with potential adverse effects that allocation techniques may have on the important float-trip-user desire to get away from the pressures and involvements of everyday life.

STUDY DESCRIPTION

The Middle Fork of the Salmon River, a component of the National Wild and Scenic Rivers System, was selected as the setting for this study because (1) its recreation use characteristics are typical of those found on other whitewater rivers around the Nation, and (2) the river has an established lottery allocation program that has been in effect since the early 1970's.

During the 1978 river floating season, data were collected by means of a self-administered questionnaire distributed to commercial and private users randomly sampled immediately following their river float trip and to a systematic random sample of rejectees (individuals who had submitted an application for a private trip permit and were subsequently "rejected" in the lottery). The questionnaire contained the following five components: (1) user preferences for allocation techniques, (2) experience expectations, (3) general float trip characteristics, (4) previous experience of users, and (5) user demographics. A total of 1,451 individuals were sent questionnaires; 1,166 were returned for an overall response rate of 80 percent. In the allocation portion of the questionnaire, respondents were asked to rate the following seven allotment techniques and six rationing techniques on a five-point Likert-type scale.

Allotment Techniques

1. *Test river.*—One river could be selected as a "test" river with no limit on the number of parties that could float it. Then, the percentages of use that naturally occur on this test river (for example, 60 percent commercial use and 40 percent private use) could be applied to whitewater rivers such as the Middle Fork.
2. *Historical use.*—Historical use levels could be employed. For example, assume that the USDA Forest Service first set a limit on Middle Fork use in 1978. If it turned out that records of past use showed that private parties made up 60 percent of the use and commercial parties made up 40 percent, these would be the percentages applied to 1978 and the future.
3. *Even split.*—Regardless of how use percentages developed in the past, a management agency could divide use by making a 50-50 split to the private and commercial users.
4. *Even-pool.*—A variation of the 50-50 split might be used. If either the commercial or private sector did not have enough demand to fill its 50 percent of the use limit, the leftover amount of use would be available for the other sector to use. However, the following year the system would begin all over with the 50-50 split.
5. *Percentage of disappointment.*—Equal percentages of people from each sector could be allowed to go down the river. For example, assume that for one particular year demand for private trips on the Middle Fork was 1,000 people and for commercial trips was 3,000 people. If the total use limit was only 3,000 people, then:

75 percent of 1,000 private users could go =	750
75 percent of 3,000 commercial users could go =	2,250
The total equals the use limit, or	3,000.

6. *Treat everyone the same.*—Commercial and private users could all be handled in the same manner, i.e., **all** potential users would first have to obtain a permit from the managing agency. Then, those who are successful would contact a commercial outfitter or organize a private trip.
7. *Middle Fork system.*—Use the system presently employed by the USDA Forest Service on the Middle Fork. (Respondents were informed that for the 1978 season the commercial sector was alloted 46 percent of the use limit and the private sector was alloted 54 percent).

Rationing Techniques

1. *Lottery.*—Use a lottery (i.e., "draw the applicants' names from a hat").
2. *Knowledge and skill requirements.*—Give priority for permits to those who meet wilderness knowledge and skill requirements.
3. *Advance reservation.*—Use advance reservations by mail, phone, etc., with early requests favored over later ones.
4. *Priority for first time users.*—Give priority for permits to those who have not floated the river before.
5. *Lottery-reservation.*—Use a combination system such as distributing half the private permits by a lottery and the other half by advance reservation (phone or mail, etc.).
6. *Priority for Idahoans.*—Give Middle Fork permit priority to Idahoans.

The response categories ranged from **very poor** (+1) to **very good** (+5). The allotment and rationing techniques were developed from a special workshop on river recreation use allocation.

A six-item scale termed Stress Release/Escape (SR/E) adapted from Driver (1977) was employed to measure the individual's expectation that the float trip would provide an outlet for release and escape from the pressures of everyday life. The scale items were randomly distributed with items from five additional scales to (1) provide data on additional float trip expectations with which to assess the relative importance of SR/E, and (2) conceal the principal motive behind the SR/E scale. A five-point Likert format was also used for the expectation scales. Response categories ranged from **not at all important** (+1) to **extremely important** (+5).

RESULTS

Allocation Preferences

Allotment techniques

The technique most preferred by commercial river floaters was the current Middle Fork System, and the technique most preferred by private river floaters and rejectees was Even-pool (table 1). The differences between the most preferred technique and the second most preferred technique were small for all groups. All groups rated Test river as the least preferred technique.

The overall order in which river floaters and rejectees ranked techniques was similar. Each group tended to favor those techniques that, apparently, would provide them with better chances for river floating opportunities or with which they were familiar. It is also noteworthy that only two or three techniques were rated poorly by a majority in each group. This suggests that managers have considerable flexibility in selecting an acceptable allotment technique.

In light of the favored status of Even-pool and the Middle Fork System, it should be noted that there are two fundamental similarities between these allotment methods. First, the initial 50-50 allotment of Even-pool is comparable to the near 50-50 allotment of the Middle Fork System. Second, the redistribution under Even-pool of surplus portions of one sector's allotment (to handle excess demand in the other sector) is similar to a provision of the Middle Fork System that allows some transfer of unused float trip opportunities between sectors.

Rationing techniques

All groups were asked to rate rationing techniques although such techniques are usually limited to the private sector. Commercial river floaters were included because it is conceivable that they may take a private float trip in the future and because the rationing technique employed may influence the availability of commercial floating opportunities.

Commercial users rate Advance Reservation the highest and Knowledge and Skill Requirements second (table 2). Private users and rejectees (i.e., those respondents directly affected by private permit rationing) also rate Knowledge and Skill Requirements second, but their most preferred choice is Lottery. Least acceptable to all respondents is Priority for Idahoans. Both a majority of commercial and private groups found that the same four rationing techniques were acceptable— Advance reservation, Lottery, Knowledge and Skill Requirements, and Lottery-Reservation. Rejectees, however, found only the Lottery and Knowledge and Skill Requirements techniques acceptable. It is interesting to note that the rejectees apparently are not disenchanted with Lottery as a rationing technique. In sum, then, the preferred techniques of all groups are consistent with the systems under which each operated in 1978, i.e., the outfitters' advance reservation (and pricing) system for the commercial users and the USDA Forest Service's lottery for the private users and rejectees.

Table 1.—*Respondents giving acceptable ratings to allotment techniques*[1]
(In percent)

Allotment technique	**User type**			**X^2 (significance)**
	Commercial	**Private**	**Rejectee**	
Test river	25	18	15	$p = 0.0005$
Historical use	65	48	42	$p < 0.0001$
Even split	53	49	52	$p = 0.0560$
Even-pool	87	78	76	$p = 0.0160$
Percentage of disappointment	78	52	47	$p < 0.0001$
Treat everyone the same	30	57	55	$p < 0.0001$
Middle Fork system	92	77	64	$p < 0.0001$

[1] An evaluation of **okay**, **good**, or **very good** constituted an acceptable rating for an allotment technique.

Table 2.—*Respondents giving acceptable ratings to rationing techniques*[1]
(In percent)

Rationing technique	User type			X^2
	Commercial	Private	Rejectee	(significance)
Lottery	57	80	92	$p<0.0001$
Knowledge and skill	66	56	51	$p=0.0005$
Advance reservation	84	54	32	$p<0.0001$
Priority for first time users	43	36	43	$p=0.0180$
Lottery-reservation	52	53	38	$p=0.0130$
Priority for Idahoans	21	23	17	$p<0.0001$

[1] An evaluation of **okay**, **good**, or **very good** constituted an acceptable rating for a rationing technique.

Allocation Preferences and User Expectations for Stress Release/Escape

A primary function of river management is to provide satisfactory recreational experiences consistent within overall policy constraints. Driver and Brown (1975) indicate that it is important to identify the social psychological outcomes visitors anticipate from their experience. These expected outcomes can then be used to estimate the impact management actions may have on recreational experiences. Driver (1977) has developed a number of scales that tap many of the expectations held by recreationists. These include solitude, action/excitement, achievement, status, affiliation, learning/discovery, and stress release/escape.

Because allocation techniques of the type discussed in this paper are direct regulatory actions, a number of analysts of the allocation issue are concerned as to whether or not such techniques will impinge on recreationists' desires for "getting away from it all". To address this issue, commercial and private users were asked to respond to a six-item scale measuring this dimension of their anticipated experience. Rejectees were not included in this portion of the study because we were only interested in individuals who had expectations of a specific floating experience.

Factor analysis was used to determine if the scale items used to measure the Stress Release/Escape (SR/E) expectation did so in a manner consistent with the findings of previous studies employing similar techniques. The extracted factor of SR/E contained five of the six original scale items plus one item initially associated with a solitude expectation scale. The items in the SR/E scale possessed a reliability coefficient of $\alpha = 0.83$. Of the five expectations measured, SR/E was the second highest in importance.

We assumed that river floaters for whom SR/E was important would view restrictive use mechanisms more negatively than floaters for whom SR/E was unimportant. In other words, the group scoring higher on SR/E would be more sensitive to regulatory actions and, therefore, would tend to give lower ratings to allocation techniques.

Examining the differences for the 13 allocation techniques revealed that there were 10 (or approximately 77 percent) for which private users gave lower ratings than commercial users. According to the above reasoning, it was hypothesized that private users would score higher on the SR/E expectation than the commercial users. However, results of the t-test employed to test this hypothesis, shows that it is not supported. The groups' scores differ in the opposite manner of that hypothesized—the commercial users scored higher on SR/E. Such an outcome suggests that the differences in commercial and private users' SR/E expectations do not explain their differences in allocation ratings. Rather, some other factors that distinguish the commercial and private users are responsible for the differences between ratings.

Although the two groups showed little difference in their desire to use the float trip as an escape from everyday life, it is possible that within each group a negative association exists between the strength of this desire and the individual's rating of allocation techniques. It is also possible that some techniques may show a higher negative association than others because some techniques may be perceived as more regulatory than others. For example, respondents may feel that rationing use by Knowledge and Skill Requirements, with associated testing, licensing, and enforcement procedures, may be inherently more regulatory than Lottery. If so, we would expect to find a higher negative association between SR/E and the former technique than between the latter. Pearson correlation coefficients were calculated to test this hypothesis.

Only one correlation coefficient demonstrated any significance— the correlation of SR/E scores of the commercial users with their ratings for the Percentage of Disappointment (PD) allotment technique (table 3). Even this weak correlation is positive rather than the hypothesized negative. Consequently, no practical relation exists between SR/E experience expectations and allocation ratings of commercial and private users.

There are several possible explanations for the lack of a relation between the individual's desire to escape from the everyday world and preferences for use allocation techniques. It is possible that the scale is not valid. However, the extensive use of the scale in many different situations makes this explanation questionable. Or, floaters may feel that allocation techniques are necessary to provide a setting in which they can escape from it all. It is also possible that individuals who hold high expectations for SR/E and who are sensitive to use allocation techniques no longer float the Middle Fork because of their perception of the amount of regulation. The great variation in SR/E scores found and the high status usually placed on a Middle Fork float trip, however, would seem to discount this explanation.

Finally, it may be that floaters discriminate among different segments of the river trip experience and the impact of management on each. Using a system similar to the one proposed by Clawson and Knetsch (1966), the trip may be broken into three segments. The initial or pretrip segment involves such things as planning, preparation, and travel to the river. The on-site segment in which the river running activity occurs and in which expectations are realized is next. The post trip segment is third and includes travel from the river, reinvolvement in everyday life, and reflection on the entire experience. User recognition of these segments to their overall float trip experience is suggested by the SR/E and allocation preference data.

Middle Fork users appear to associate allocation techniques with only the pretrip portion of their experience and to relate SR/E with only the on-site portion. This makes sense, because the allocation techniques discussed in this paper have their direct effect on such pretrip involvements as planning and preparation. Once an individual makes it into the system, the expectations for escape may be reinforced and strengthened. Satisfactions of such expectations would be influenced principally by on-site management.

SUMMARY

The commercial users, private users, and rejectees had distinct preferences among the 13 allocation techniques presented to them. Overall, the most preferred allotment technique for all three groups was Even-pool. The Middle Fork System was also highly favored by all groups. The most acceptable rationing technique for the commercial users was Advance Reservation; Knowledge and Skill Requirements was rated second. Although private users and rejectees also gave this latter technique a second-place ranking, the most acceptable rationing technique for them was Lottery.

Table 3.— *Pearson correlation coefficients between commercial and private users's scores for stress release escape and their ratings for allocation techniques*

Subpopulation	Allotment technique[1] ratings							Rationing technique[2] ratings					
SR/E scores	TR	HU	ES	EP	PD	ETS	MFS	L	KS	AR	PFU	LR	PI
Commercial users	0.01	–0.02	–0.02	0.05	0.11[3]	0.04	–0.05	–0.02	0.02	0.05	0.01	0.03	–0.05
Private users	–0.05	–0.00	0.03	–0.01	–0.07	0.05	–0.01	0.07	0.05	0.05	–0.01	–0.00	–0.06

[1] TR = Test River, HU = Historical Use, ES = Even Split, EP = Even-pool, PD = Percentage of Disappointment, ETS = Everyone the Same, MFS = Middle Fork System.

[2] L = Lottery, KS = Knowledge and Skill Requirements, AR = Advance Reservation, PFU = Priority for First Time Users, LR = Lottery-reservation, PI = Priority for Idahoans.

[3] Significant at the 5 percent level.

The data suggest that concern for possible negative consequences of direct allocation techniques on river floaters' SR/E experiences may be unfounded. No relation appears to exist between Middle Fork floater SR/E expectation scores and their preferences for allocation techniques. It is assumed that other factors explain the underlying reasons for floaters' allocation preferences. This conclusion is similar to the findings of Schreyer and Nielson (1978). These researchers compared floaters scoring high on a stress release/solitude scale against those scoring low according to the users' ratings of four different allocation techniques. For three of the techniques, no significant rating differences were found. In the case of the one technique for which a difference was identified, the difference was small.

However, Schreyer and Nielson (1978) did find significant correlations between stress release/solitude expectations and on-site management activities. These data support our hypothesis that river floaters may psychologically segment the experience and be sensitive to the impact of different techniques on each segment. Certainly, further research to explore this hypothesis would be useful.

The data suggest several characteristics of allocation techniques that may be preferred by floaters in other similar whitewater settings. Acceptability of a technique may be influenced by the familiarity floaters have with the technique and by its inherent sense of fairness. The extent to which the technique does not impinge upon the pretrip planning segment of the experience may also be influential. Finally, users may prefer those techniques that would tend to enhance or at least maintain their chances for future participation in a float trip.

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DISPLACEMENT OF USERS WITHIN A RIVER SYSTEM: SOCIAL AND ENVIRONMENTAL TRADE-OFFS

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BACKGROUND

The nature of the recreation relation between people and resources is extremely varied and dynamic. How these relations affect the quality of natural areas and enjoyment of area users has been the focus of outdoor recreation research since the early 1960's. During the 1960's, it became apparent that it was no longer sufficient to think in terms of facilities alone when considering quality in outdoor settings—the quality of the recreational experience had to be considered as well (Lucas 1964). The extent of national concern over the consequences of increasing use of our Nation's natural, scenic, and recreational resources was highlighted in 1968 by the passage of the National Wild and Scenic Rivers Act (P.L. 90-542):

> It is hereby declared to be the policy of the United States that certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations.

However, the enactment of this legislation has not, thus far, succeeded in protecting our river systems from damages due to overuse. On the contrary, it is argued that national designation may have accelerated the degradation of the characteristics that the Act was designed to preserve because we have focused on protection from development and not from recreational use.

Faced with increasing use levels, managers have sought to determine and prevent the resulting impacts by conducting site-specific studies and implementing site-specific remedies. This piecemeal approach has been inefficient and has led to erroneous conclusions regarding the use of these resources, resulting in inappropriate management decisions. At present, however, the managers of our natural resources have few alternatives. They are required to pursue the potentially conflicting goals of preserving their natural area and promoting its use. This dilemma is particularly disrupting to riverways, due to interconnectedness of river systems, the wide variety of potential uses, and the multiplicity of jurisdictions normally present along river corridors.

Because it is difficult and often undesirable for any one recreational area to provide the full range of recreational experiences, a limited set of management objectives are suggested that enhance specific opportunities appropriate to the resource base. Choosing such management objectives, however, is a legal and political nightmare.

To provide a foundation for resource management decisions, researchers and managers have invested substantial effort in relating resource quality to area utilization. Recognizing the complexity of recreation use on natural areas, researchers and agencies have offered a series of conceptual and methodological frameworks for addressing the problem. Because the issue concerns escalating demand for a finite resource base, models that associate demand for recreation with the capacity and limitation of the resource have become increasingly popular. Although assuming a wide variety of approaches, these studies have become generically known as recreational carrying capacity.

Recreational Carrying Capacity

Recreational carrying capacity has been defined as the level at which an area, having a characteristic use, can be supported (with the possible inclusion of development) over a specified time without causing excessive damage to either the physical environment or the experience of the user (Lime and Stankey 1971). Early carrying capacity work followed econometric lines (Cicchetti and Smith 1973, Fisher and Krutilla 1972), which hypothesized a negative association between individual satisfaction and the number of user contacts in a wilderness area. The popularity and use of the econometric model is understandable given the roots of the carrying capacity concept. Carrying capacity developed as a range management concept that involved a negative consequence to a population as a result of overuse of a feeding range (Heady 1975). Obviously, the impacts of recreational "overuse" do not have similar overt impacts on the user. In this search for recreational use consequences, the focus centered on the principal product of recreation—user satisfaction.

Satisfaction as a Variable

Two related concepts are used to understand satisfaction—expectancy and discrepancy. As described by Schreyer and Roggenbuck (1978) expectancy is the "...belief that a particular act will be followed by a particular outcome...Recreation may be considered an activity in which individuals engage with the expectation of certain rewards such as excitement, [and] solitude...." Discrepancy is the difference between the expected and the actual outcomes. Dissatisfaction results from expectations that are not realized. Conversely, fulfilled expectations ensure satisfaction.

The use of satisfaction as a consequence variable in outdoor recreation is grounded both in leisure theory and common sense. However, when used to explain specific attributes of specific user groups at specific sites, findings have not supported the econometric hypothesis. Indeed, numerous researchers have reported no significant relation between area density and user satisfaction. Shelby and Nielsen (1975) reported user stated satisfaction uniformly high on the Colorado River regardless of the user density on that river. Similar results have been reported by Heberlein and Vaske (1977) on Wisconsin's Bois Brule River, and Blackwood (1977) on Wisconsin's Wolf River. However, because the above studies utilized similar methodologies and were specific to a single resource, a question exists regarding interpretation of findings. Specifically, if no relation exists between area use density and stated user satisfaction, then application of the econometric model suffers from the exclusion of one component, that is, user adaptation to increasing contact levels. However, if as Schreyer (1979) pointed out: increasing use alters the definition of the experience (thereby displacing those no longer desiring the new experience, with new users accepting the encountered situation) then the inverse relation between area density and user satisfaction would be correct when viewed beyond a specific site at a specific time, with user displacement as the negative consequence.

Concept of Displacement

Displacement is a move away from an unacceptable situation rather than a move toward an optimal one. This distinction is useful in separating displacement, a form of reactive movement, from other forms of movement behavior. Among the other forms of movement behavior are: (1) Active migrations. Users methodically seek a suitable destination according to their values. Groups typifying this form of behavior can be illustrated by white-water canoeists who seek a variety of skill-test, risk-seeking outlets. Within this group, the movement is a part of the experience, i.e., "doing" a specific set of rivers. (2) Passive migration. Users elect a location as a result of constraints external to their individual expectations or preferences. Visiting areas to meet friends for picnics, choosing locations because other members of the participation group desire those locations would fall into this classification. (3) Diurnal requirements of an activity. Users relocating within sites to accommodate requirements of an activity. Fishermen moving to different locations on a lake at various times represent such movement. The motivation of the movement is dictated by the requirements of the activity. The movement of the fish rather than movement as a reaction to negative characteristics of the site dictates user location.

Movement behavior is then a general rubric, while displacement is a specific component characterizing negative reactive movements. Adjustments of use both in time and space are involved. Figure 1 represents this relation, as use increases users' expectation curve shifts. In other words, the type of person for whom the curve is based keeps changing, a process

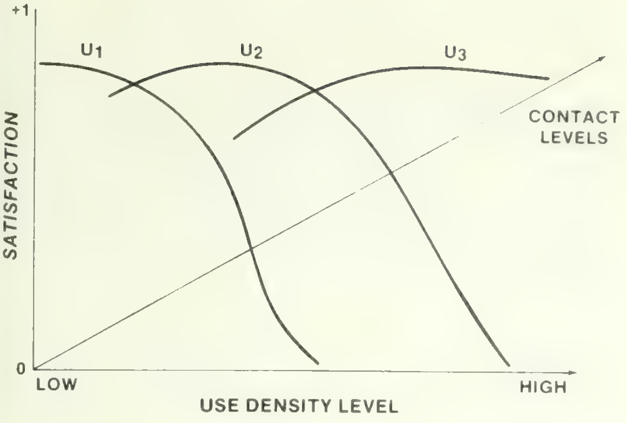

Figure 1.—*Conceptual relation between satisfaction and area density with displacement where:* U_1 *= low density oriented users.* U_2 *= users preferring some social contacts.* U_3 *= high density tolerant users (these user group curves represent an array of curves along a user density tolerant continuum) As area use density and subsequent user contacts increase, the specific site begins to attract users tolerant of the escalating human use. They replace previous site users in a successional fashion.*

that may never end if based solely on social criteria. Thus, managers cannot find the carrying capacity by measuring satisfaction. They will be continually measuring satisfaction of a different user, i.e., one who enjoys the current situation.

Again, a number of river studies (on the Wolf, Colorado, Brule, Namekagon, etc.) have shown that at any given point in time, on any river, the majority of the users will say they are satisfied with their experience. That is, in a one-time, site-specific experience study, the dominant response will be yes, we are satisfied. Simply by being at that river, the majority are accepting the situation at that site at that time.

It is to be expected that those who are dissatisfied with their experience will eventually do something about it—change the day or time of day of a visit, change the location on the river of the visit, change rivers, or change activities entirely. So the question is not "who is satisfied now with their experience on a river", but "are those who are satisfied now the same group that was satisfied 5 years ago on this site—and, if not, where have these people come from and where have the others gone?" To answer such questions one-river studies must be tied into the context of other similar rivers in the same region and thus into the concept of movement behavior, or displacement. These questions may also be addressed by a longitudinal examination of specific users.

So the basic observation behind displacement is that people leave. New users come in, change a site by the nature of their behavior and activities, and affect the experience of the other users. One of the driving forces that sets this succession of users in motion appears to be perceived density (Becker, 1978a). On a site where use is increasing, those new users who stay tend to be tolerant of encountering other people, whereas those who leave tend to be intolerant of encountering other people and change their visits to the river in time or location, change rivers, or drop out altogether. As will be discussed, the combination of the Lower St.Croix/Upper Mississippi studies was able to pick up just such movement.

STUDY METHODOLOGY AND LOCATION

The purpose of this study was to examine users from both the Upper Mississippi and Lower St. Croix Rivers for evidence of displacement. Specifically, the study objectives were:

(1) determine the extent user densities affect choice of river location and time of visit for various user groups;

(2) determine criteria individuals use for evaluating preference for specific rivers; and

(3) determine the extent satisfaction, as a variable, is usable for area managers.

During summer and fall of 1977 and winter of 1978 user studies were conducted on the Lower St. Croix Wild and Scenic River (Becker *et al.* 1979) and the upper reach of the Upper Mississippi River (Pools 1 to 10) (Becker 1978b). Approximately 3,400 questionnaires were distributed to transient on-site users of both rivers and to Lower St. Croix riparian landowners.

Questionnaires to transient users were distributed on two separate schedule forms. The two forms represented various question areas. The forms were distributed using the same sampling scheme and served as a replicated measure for reliability checks. Questions that were identical on both forms were collapsed for aggregate sample presentations for each river. The surveys for each river user group examined user attitudes and perceptions and were related to riverway use. Additional questions designed to examine use pattern variation, use levels and user satisfaction, and user expectation were included.

On the Lower St. Croix River, interviews were conducted at both random and selected sites between Memorial Day and Labor Day. On the Upper Mississippi, interviews were conducted at islands, sandbars, and beaches between St. Paul, Minnesota, and Guttenburg, Iowa, from June 21 through October 10. For this paper users interviewed after Labor Day were excluded from the analysis. Sampling was conducted on a constructed season technique—questionnaires were distributed at each site during various times of the day and days of the week in proportion to the summer season.

The Lower St. Croix

The Lower St. Croix has been a part of the National Riverways System since 1972. The St. Croix is the only national riverway protected from its origin to its confluence. It is administered by the National Park Service and the Departments of Natural Resources of Minnesota and Wisconsin.

The Upper Mississippi

From the beginning of use of the Mississippi River, it has been considered in two sections: the Upper Mississippi and the Lower Mississippi, with the point of demarcation Cairo, Illinois, where the Ohio River enters. Both the Upper and Lower sections have stretches where, by characteristics, and/or use, one is distinct from the other resulting in further subdivisions. The concern of this particular study is that part of the Upper Mississippi from the Twin Cities in Minnesota to Guttenburg, Iowa.

RESULTS

Displacement Between the Lower St. Croix and Upper Mississippi

Analysis involved comparisons of users on different resource bases. This comparison is essential if users of a resource have shifted or left one area for another to achieve a favorable social experience.

If the hypothesis regarding displacement is correct, users would shift to areas that afforded a satisfying experience. Thus, when taken as separate settings, users of both the Lower St. Croix and Upper Mississippi should reveal uniformly high levels of satisfaction regardless of area density or use. This is indeed what we found—both Lower St. Croix and Upper Mississippi River users reported similar high levels of satisfaction (table 1.)

Table 1.—*Stated satisfaction of river users: responses to the question, "How would you rate your visit to the river today?"*

Response	Upper Mississippi		Lower St. Croix	
	No.	*Percent*	*No.*	*Percent*
Poor	9	1	9	1
Fair	64	4	139	7
Good, but I wish a number of things had been different	202	12	171	10
Very good, but could have been better	274	17	276	16
Excellent, only minor problems	626	38	614	36
Perfect	467	28	513	30

t=-0.83

Further analysis of users on both the Lower St. Croix and Upper Mississippi River centered on those individuals who had experiences on both rivers but had expressed a preference for one. These persons were extracted from individuals responding to the regional follow-up questionnaire. Individuals were asked to identify if they preferred either the Lower St. Croix or the Upper Mississippi. Those selecting either river were then directed to one of two qualifying questions.—"If you used to visit the Lower St. Croix, why do you no longer visit there?" or "If you used to visit the Upper Mississippi from St. Paul to Guttenburg, Iowa, why do you no longer visit there?" Users familiar with both rivers both preferring the Upper Mississippi identified the following elements as reasons for no longer visiting the Lower St. Croix River: too crowded, too few public beach areas, unsafe boat operation, and too few public facilities. Users familiar with both rivers both preferring the Lower St. Croix identified the following elements as reasons for no longer visiting the Upper Mississippi: water polluted, unsafe swimming, litter and debris, and barge traffic.

CONCLUSIONS

Users on both the Upper Mississippi and the Lower St. Croix Rivers were equally satisfied with their experience. During summer of 1977 the Lower St. Croix had approximately 800,000 visitor days over its 52 miles. During this same period the 300 + miles of the Upper Mississippi had approximately 300,000 user days. If viewed as individual (unrelated) rivers, findings would appear to sustain the idea of no relation between area density and user satisfaction. However, when viewed as a system, findings sustain the idea of user movement to achieve a desired social experience or environmental setting.

This paper suggests several types of displacement occur on the Lower St. Croix and upper reaches of the Upper Mississippi Rivers. Users and riparian landowners are purposefully avoiding areas and periods of the day and days of the week with high use levels.

Given a course of events that allows use levels to increase and subsequently managing for these higher levels will result in only density-tolerant activities and people remaining. Some persons will either be excluded from participating or be forced to shift their expectations and activities. Knowledge of this process demands recreation managers decide who they want to create what type of experiences for, and then implement measures to ensure its occurrence. If we, as a society, care to offer a full continuum of recreational experiences, we must take a broad perspective—temporally and spatially—and administer recreational areas for different types of experiences and activities.

The Lower St. Croix with its status as a nationally significant river should be managed to enhance and preserve those experiences that made it desirable for designation. Preservation cannot stop with management of the resource base in isolation to the human experiences the area provides. It is of course feasible to allow use on the Lower St. Croix River to continue to grow and in the course of such growth provide satisfying experiences for large numbers of individuals. But the inclusion of larger numbers of users will iteratively remove individuals sensitive to increasing densities and continue to alter the social qualities now present on the river. User movement from the Lower St. Croix River to the Upper Mississippi River will continue in the absence of a unified regional management plan. The politically popular management theme "preado optimum," the greatest good, must incorporate definitions of good beyond strikingly large numbers.

Thus, every site cannot be everything to everybody. A wild and scenic river should be the setting for an array of experiences that differ markedly from a developed multiple use river. Similarly, an area designated to promote social interactions and accommodate large numbers of people in an outdoor setting should not be managed to accommodate individuals seeking a low density, solitude-oriented experience. To attempt such mergers on a single area will result in a loss of both social and natural diversity.

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VISITOR IMAGES OF NATIONAL PARKS: THE INFLUENCE OF SOCIAL DEFINITIONS OF PLACES ON PERCEPTIONS AND BEHAVIOR

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Recreation participation often depends upon a specific setting, which may represent a key aspect of the recreation experience. While some environments may appear generalized in the mind of the user (e.g., a local park), others may be strongly imbued with meaning and seen to possess highly specialized characteristics (e.g., Bryce Canyon National Park). As images held by participants may affect their behaviors (Lee 1972), their satisfaction (Schreyer *et al.* 1976), and their potential to conflict with others (Jacob 1978), it is valuable to understand the nature of such images.

Personal definitions of recreation places are the result of either direct experience (Tuan 1978), indicating the functional role of the environment in fulfilling expectations (i.e., the capacity to meet one's needs), or of socio-cultural value messages (Berger and Luckman 1966)—for example, National Parks are a part of our "cultural heritage." It is likely that an image will consist of a dynamic interaction process between these two dimensions (Neisser 1976).

A major issue concerns how the differing nature of images held of a given environment affects behavior in that environment. Such differences may be useful in understanding the environment-behavior link, and could conceivably be linked to environmental management. Stankey (1972) has suggested that users of wilderness areas may be identified by their degree of "wildernism"—that is, by the degree to which their attitudes and beliefs concerning wilderness match the specific purpose and intentions of wilderness legislation. In this sense, "image" was defined by a particular set of characteristics—those described in the Wilderness Act. Although this is not the full range of dimensions by which people define wilderness, it gives a means of linking image to administrative concerns. Thus, Stankey proposed that management should follow the preferences of those whose environmental images most closely matched the definitions created in the Wilderness Act. Stankey has provided data indicating that users could be distinguished by their degree of "wildernism," and that these differences were linked to differing behaviors, backgrounds, and preferences for management situations (Stankey 1971).

The purpose of the present study was to explore the extent to which such an image exists for National Parks. That is, does a dimension of "parkism" exist that may be defined through extractions of legislative intent? Can such a dimension distinguish among different types of users or their backgrounds? Are such differences linked to various expectations for recreation experiences? Finally, can such a dimension differentiate among users' preferences for strategies of management? To explore these relations, a study was carried out in a Park Service area that was also considered a wilderness. Comparative analyses were therefore made concerning users' degree of "wildernism" and "parkism" to explore links to background, behaviors, perceptions, and attitudes. Users studied were involved in taking float trips on the Green and Yampa Rivers in Dinosaur National Monument.

METHOD

The Study

During the summer of 1975, a questionnaire was distributed to river recreationists as they disembarked from their trips. The questionnaire was to be completed upon returning home and mailed back in a postage-paid envelope. It asked respondents' attitudes concerning management strategies for the monument, perceptions and evaluations of encounters with others, a scale measuring experience expectations, and background and trip-related variables. A systematic random sample was stratified by day vs. overnight user. Three 4-day sampling clusters were employed for each of the four major use months of May, June, July, and August. A total of 1,141 questionnaires were distributed. Two follow-ups yielded 854 usable returns, representing a 76 percent response rate.

Wildernism

A Likert-type scale of 27 items concerned the purposes and appropriate uses of wilderness. A final scale of 17 items was ultimately developed using the following criteria: items that could separate users were sought in order to make a more refined measure. If a question was so general that everyone could agree with it, its utility as a measure of differing conceptions of wilderness would be of little value even though it related to a real aspect of wilderness. Average scores were computed for each individual, ranging from 1 to 5, with the latter indicating strong agreement with the legislative conception of wilderness.

Parkism

The development of a scale to measure a National Park construct proved to be far more difficult. Park Service mandates are often couched in broad generalities, in terms of the uses and experiences felt to be appropriate. Even though an experience is being defined, it is certainly much more diverse and vague than the wilderness concept. "For the benefit and enjoyment of the people" leaves considerable leeway for interpretation. A search was made of the literature to find common themes. Conceptions of the values and appropriate uses of national parks and monuments have tended to evolve over time. Further, values tend to be placed in the broadest possible phrases, making it difficult to find statements that people would vary on.

Fifty-three items were pretested, resulting in the selection of 27 for the questionnaire. As with wildernism, 17 items were ultimately used for the actual index, based on the separation of user evaluations. Seventeen items were used so that both indices would be of equal size, though this was not really necessary for scale validity. Wildernism scales were shown to be valid, but the concept of parkism was much more tentative. Because the scales were intended for application with other management-related questions in the study, the greater strength of the wildernism scale was used as a rationale for giving it a wider exposure. The wilderness scale appeared in questionnaires distributed from May through July, while the parkism scale appeared in questionnaires distributed in August. Such a method may be subject to potential bias through differences in users across time. The smaller number of users rating the parkism scale could also reduce the reliability of the results analyzed with this scale. A total of 657 respondents received wildernism scores, and 200 respondents received parkism scores.

RESULTS

User Identification

Both scales distributed users along the range of average scores. The range for mean wildernism scores was from 1.0 to 5.0, with five individuals obtaining the maximum score. The median score was 3.4, indicating a shift toward the high end of the spectrum. Scores were divided into three classes of High, Medium, and Low Wilderness purism scores, with the middle group containing 50 percent of the sample and each extreme representing 25 percent. For the sake of convenience, the High, Medium, and Low Wilderness groups will subsequently be referred to as HW, MW, and LW, respectively. The range in values for the categories were 1.0 to 3.0 for the LW, 3.01 to 3.85 for the MW, and 3.86 to 5.00 for HW.

The range of responses for the park purism score ran from 1.0 to 4.73, slightly less than the range for the wilderness scale. The median score of 3.84 shows a much stronger shift toward the "park purism" end of the scale. Again the three categories of High Park Purism (HP), Medium Park Purism (MP), and Low Park Purism (LP) were created. The range for the LP was 1.0 to 3.50, accounting for 25 percent of persons scoring on the scale; 3.51 to 4.10 for the MP, accounting for 51 percent; and 4.11 to 4.73 for the HP, including 24 percent.

No relation was found between wildernism score and age or income level. However, a significant positive relation existed between the score and amount of education. This finding is consistent with findings of high education levels among wilderness users (Hendee *et al.* 1968). Persons taking different types of trips also differed in wilderness scores (table 1). Persons on private float trips—ran the trip themselves using their own equipment—tended to be more highly represented in the HW class, and those on commercial trips—guided down the river by a professional outfitter—tended to be more highly represented in the LW category. Persons on "educational" trips—those sponsored by educational institutions—tended to have intermediate scores.

Results of analyses broken down by the three park categories showed that few significant differences exist to characterize the groups. The only background variable showing a significant difference was, like wildernism, education. However, the highest category was not HP, but rather MP. This tendency for the MP category to register the most extreme response was noticed in other situations as well. The difference could be purely a chance distribution; alternatively, more highly educated individuals might be more likely to take moderate positions on the generalized value questions that form much of the scale. In most cases the differences between the HP and MP were small; the largest differences were seen between these two and the LP group. There is no way to distinguish the different categories of parkism by the kind of trip (commercial, private) individuals in the various groups selected.

The Nature of the Experience

Seven scales measuring respondent expectations for the particular recreation experience were developed following the methods created by Driver (1977). An examination of the experience expectations of the three wilderness groups shows some distinctive differences (fig. 1). A comparison of HW and LW categories shows some divergences in directions that might have been expected. The action-excitement expectation is high for everyone, but not as high for HW's as for LW's and MW's. The person who has strong wilderness values tends to equate the nature and excitement components, while those at the lower end of the scale place more importance on excitement.

Solitude is an important wilderness value, and the data show some trends that suggest support for this value. For affiliation, the HW's scored lowest and the LW's highest. Further, HW's felt stress/solitude to be a more important motive than LW's.

The status scale shows some of the strongest differences—HW's gave it a far lower rating than MW's or LW's. This may suggest that attunement to wilderness values are more likely to be seen as ends in themselves, and side benefits such as prestige may be less important. Two scales, autonomy/achievement and self-awareness, did not show differences among the categories. These values were less important to persons on float trips in general, and therefore may not be tied up with values related to participation.

For the National Park scale, two of the experience expectations showed significant differences among the groups. The first is experiencing nature. The[1] MP and HP categories both registered higher than the LP score (4.04), with the MP (4.49) being virtually the same as the HP (4.47). This difference makes sense if one assumes that persons who support values consistent with National Parks will be more attuned to experiencing nature. The second experience expectation is autonomy/achievement. The MP had the highest score (2.83), LP was second (2.68), and HP was

Table 1.—*Trip type for persons in the three wilderness categories*

Trip type	Wilderness category						Total
	LW		MW		HW		
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*
Commercial	123	73	197	62	84	49	404
Educational	24	14	68	22	31	18	123
Private	22	13	50	16	58	33	130
Total	169	100	315	100	173	100	657

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[1] *Scores relate to average scores of the verbal response—1 = not at all important, 2 = slightly important, 3 = somewhat important, 4 = moderately important, 5 = very important and 6 = extremely important.*

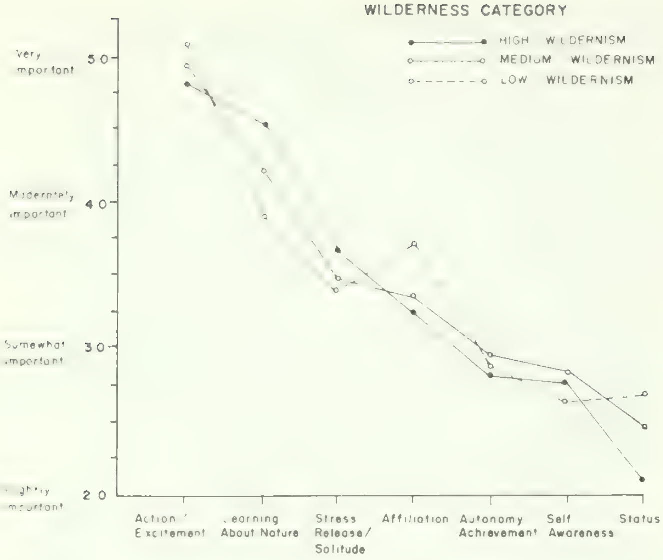

Figure 1.—*Profiles of experience expectations for the three wilderness categories.*

third (2.32). The low rating for the HP's may indicate a preference for "passive" (e.g., education) as opposed to "active" recreation.

Perceptions of Others

Users were also likely to perceive others differently depending on wildernism score. Those higher in the wildernism score were significantly more likely to feel they had seen too many people on the trip. Sensitivity was particularly high at campsites, where the Pearson correlation between numbers seen and the feeling of being crowded was $r = 0.68$ for HW and $r = 0.29$ for LW. Persons strong in wildernism were also more sensitive to the behavior of others. Three-fourths of the LW's found neither numbers nor behavior disturbing, but less than half of the HW's felt that way. Conversely, only 2 percent of the LW's and 2 percent of the MW's felt that numbers **and** behavior were disturbing, while 11 percent of the HW's felt this way. The HW's were twice as likely to consider numbers or behavior disturbing than the LW's.

The perception of crowding differed somewhat in the three parkism categories, though the limited numbers of persons in the sample make accurate interpretation difficult. The main trend was a greater sensitivity in the HP category to perception of crowding for total numbers of others encountered. However, this was not a consistent trend. The different types of people did not differ markedly in their perceptions of crowding at specific sites, nor were they more sensitive to behavior as opposed to numbers.

Preferences for Management

Perhaps the most crucial concern relating to wilderness and park orientation is whether or not the groups differ with respect to actions that managers might take to increase satisfactions or to protect the resource. Three major areas of management considered were campsite development, use distribution, and regulation.

The three wilderness groups all differed systematically with respect to their answers to questions on campsite development. HW's preferred less development and natural conditions. They did not desire to see more pit toilets and did not even want toilets cleaned more often. HW's were also strongly opposed to providing flush toilets. LW's were almost neutral on this issue. The one case in which the HW's were more in favor of an option was in the case of the suggestion to remove all toilets.

The three groups also differed in their responses to proposals for different kinds of facilities development (fig. 2). The LW and MW groups were moderately opposed to the provision of shelters for sleeping, but the HW group was almost solidly at the extreme end of the scale in opposition. The average response to the picnic tables question was to maintain the status quo. When the separate groups are examined, the HW's were somewhat opposed to removing tables and more

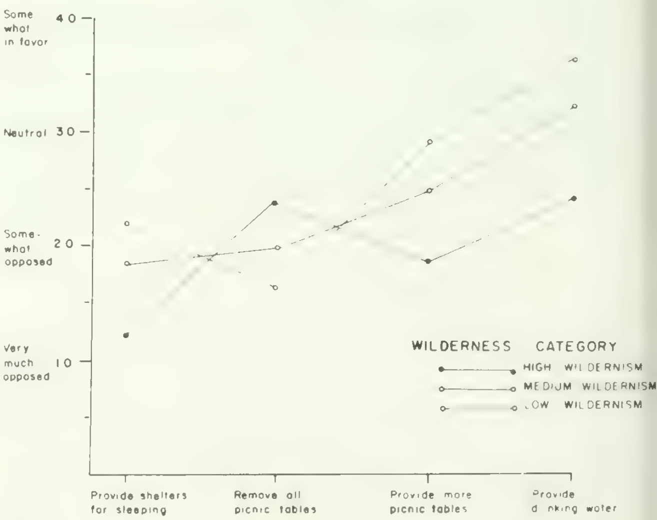

Figure 2.—*Average scores for wilderness categories for questions relating to facilities at campsites.*

strongly opposed to adding new tables. In contrast, the LW's were strongly opposed to removing the present tables but were neutral with respect to adding new tables. Providing drinking water has both strong convenience and development implications and could put values concerning nondevelopment to a strong test. As it turns out, the HW's opposed the proposal, MW's were neutral, and LW's were in favor of the proposal.

Many questions that dealt with controlling use to minimize the negative effects of crowding were not distinguished significantly by the groups. A possible reason is the lack of clarity in many users' minds concerning the possible implications of various strategies. The acceptance of any strategy depends on whether the control is more objectionable than encountering large numbers of people. About two-thirds of the LW's agreed that group size should be limited but 93 percent of the HW's felt it should be limited. Thirty-six percent of the HW's wished to see the maximum size set at less than 20 people, while 31 percent of the LW's wished to see the size set at less than 20. Twenty-eight percent of the HW's preferred a maximum group size of more than 30 people, while 36 percent of the MW's and 34 percent of the LW's felt that way. These differences are small and would probably have little or no influence on managerial decisions. All groups opposed zoning the rivers such that one would have high and one low use, though the HW's were the most strongly opposed.

The suggestion to establish more campgrounds was responded to neutrally by the HW's and MW's and somewhat favorably by the LW's. The neutral HW response is likely due to the mixed blessing of spreading out use (positive) by providing more facilities (negative). Assigning campsites was treated favorably by all groups. In this instance, the strongest positive response was recorded by the HW's. Loss of freedom in choice of a campsite may be worth minimizing camping contacts. In a similar vein, the option of an overall seasonal use limit was supported by all, but most strongly by the HW's.

Responses to the management options were analyzed in a similar manner for the parkism groups, but few options showed significant differences. None of the campsite development questions differed significantly. However, a significant relation was found in the responses to the suggestion to limit group size—63 percent of LP's, 82 percent of MP's, and 84 percent of HP's were in favor of limiting group size. Because parks are considered highly regulated and controlled environments, it is reasonable that those who support park values would tend to be more in favor of regulation to maintain park experiences.

With respect to use limitations, the HP's were most supportive of an overall seasonal use limit, while LP's were neutral. However, although all groups opposed zoning the two rivers, HP's were more opposed than the other groups. Finally, all groups were opposed to a lottery but the MP group was less strongly opposed than the other two groups.

DISCUSSION AND CONCLUSION

The wilderness value scale appears to lend support for the Stankey methodology as applied to the specific example of wilderness. In the given circumstance, a reliable scale was derived that gave consistent results. Attitudes toward wilderness values do take part in a larger framework of attitudes toward natural environments that will shape responses to suggestions for action in such areas. People who had strong wilderness values tended to be more sensitive to crowding when exposed to the same numbers of persons as other groups. Further, such individuals reacted more strongly to seeing increased numbers of people than did other groups. The HW's also supported management measures that would make crowding less obvious and opposed options designed to increase facilities.

Although the wilderness scale worked as expected, the park scale showed little to support its value. Some significant differences were observed, but there did not appear to be any consistent pattern that could be useful to interpret for management purposes. It appears that even though it is possible to construct a scale and differentiate people according to values toward parks, these values are not necessarily associated with specific attitudes toward the appropriate uses of areas.

Institutionalized definitions of places represent only one type of input to an individual's mental schema concerning those environments. Personal experience, popular literature, and one's peers may all play a significant role. That a scale for "parkism" based on formalized meanings failed to differentiate among users in any conceptually useful way does not mean that shared images of such environments do not exist or guide behavior. Rather, types of meanings must be searched for that may be more salient for the users themselves.

One may also view the results as suggesting that Park images are widely shared but extremely general. It would be useful to understand how the general image of "National Park" interacted with the specific environment of "Green River in Dinosaur National Monument." The latter may be much more useful in understanding the influence of image upon behavior. This is likely applicable to the wilderness concept as well, because many people may not view Dinosaur as much of a wilderness even though they tend to have high wildernism values.

The Parkism scale was developed using questions that would separate users rather than picking items with universal agreement. Many areas of common perception were filtered out. However, the more widely shared an image, the more general it is likely to be in definition, suggesting limited impact upon individual behaviors. Park perceptions, therefore, could be geared more to specific situations of interaction rather than toward generalized images of a very diverse system.

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POLITICS AND RESEARCH UTILIZATION: A CASE STUDY OF RIVER RESEARCH IN GRAND CANYON

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Social scientists for a long time have wrestled with the problems of applied versus theoretical research. The arguments against scientists' involvement in policy research can be summarized as follows: applications may divert scientists from their "true" priority of broadening knowledge, scientists may be pushed into premature judgments based on inadequate knowledge, the choice of issues by sponsors may distort the development of a discipline, and scientists may accept without question the sponsor's value orientations (Weiss 1977). However, most social scientists accept some overlap between science and policy. Applications of science have a long tradition and there are opportunities for theoretical advances as well as impacts on programs.

Research application means that results aren't simply absorbed into some body of scientific knowledge. Utilization, then, becomes an important issue. But the extent to which research results are "used" varies greatly. Some reports are shelved and never seen again; others become an integral part of planning and management. How is research used and what causes these differences in utilization?

The most common assumption is that policy decision-making is done rationally and linearly. A problem is identified, but the information needed to generate or choose among solutions is lacking; research provides that information and a wise decision can be made. This view, however, is usually too simplistic. The policy world is a busy place, and policymakers are in a dynamic relationship with information sources as diverse as administrators, politicians, journalists, interest groups, and social scientists. An "interactive" view of research utilization makes more sense, emphasizing that the process is at times disorderly and reiterative in spite of attempts to introduce rationality. Research is only one kind of input, and it may even be used by policymakers for purposes other than decision-making. These include delaying action, avoiding responsibility, discrediting an opponent or policy, or gaining recognition for success or support for future programs (see Weiss 1977 for a discussion of these issues).

The factors affecting research utilization can be divided into two general categories. The first concerns "scientific" characteristics of the research itself, including methodological quality, relevance and timeliness of information, and strength of findings (Cox 1977, Rossi and Wright 1977, Hawkins *et al.* 1978). Scientists tend to focus on factors in this category, particularly methodological problems such as defining research issues, designing the study, and reporting results in terms that make sense to clients. This kind of scientific integrity is also a concern of many in resource management positions (Kilgore 1978).

High quality is clearly necessary if research is to stand up in the public policy arena. By itself, however, high quality is not sufficient to ensure that results will actually be used in decision-making. Even good research sometimes gets a cool reception, and the possible reasons for this fall into a second category of "political" factors affecting utilization. These factors will be the focus of this paper.

Research is done in a political environment. The use of the word politics, particularly among scientists, conjures up images of unsavory scheming and devious tactics. But in a more ideal sense, politics can be defined as getting things done where people are involved, and this necessarily means dealing with personalities, values, budgets, bureaucracies, regulations, laws, and conflicts between interest groups. Research becomes involved with these kinds of things as it is "put to work." Political factors that may affect research utilization include (1) organizational constraints in agencies or bureaucracies, (2) the magnitude of organizational commitment required for good evaluation, (3) differences or conflicts between the "cultures" of scientists and practitioners, (4) the extent of coordination among agencies required for implementation, (5) the magnitude of risks and predictability of consequences, (6) the amount of social conflict over values implicit in proposals, and (7) the complexity of the issues involved (Bolan 1969, Cox 1977, Hawkins *et al.* 1978).

A recent paper by three river managers (Mak *et al.* 1977) indicates that resource management decisions are often made in the less tidy interactive manner described earlier. Several papers on planning suggest the same conclusion (Beckman 1964, Bolan 1969), as does my own experience with a number of research projects. The rest of this paper will be a discussion of research on the Colorado River in Grand Canyon. The next section will present a case study in order to explore the interactive nature of the decision-making process. The concluding section will draw on the case study to learn more about how political factors affect research utilization.

GRAND CANYON

The Grand Canyon has an interesting recent history. It began with problems of crowding and conflict in the late 1960's and early 1970's and has now progressed through the Final Environmental Statement (FES) on the River Management Plan. The Plan outlines a comprehensive management strategy based on research results, public involvement, and management effort. The following draws heavily from a more thorough historical review by Shelby and Nielsen (1976d).

Problems and Controversy

River runners and managers alike were alarmed by rapid increases in use (from 547 people in 1965 to 16,428 in 1972). The 1971 Draft Master Plan for Grand Canyon National Park indicated a concern for river management issues and suggested that river trips should provide a "wilderness experience." The River Use Plan issued in 1972 was an attempt to address the problem of uncontrolled use, but the Plan contained two bombshells. The first concerned **use levels**. Commercial outfitters had been allotted 105,000 user days for 1972 but had used only 89,000; they would be held to this for the next few seasons. In addition, however, the Use Plan called for a further reduction to 55,000 user days by the 1977 season.

The second bombshell involved the use of **motorized rafts**. The Plan acknowledged the issue was somewhat subjective but indicated that the goal was to provide opportunities for an intimate man-nature relation in which the river was run "on its own terms." Therefore, motor use on river trips would be phased out.

The plan was a laudable attempt to establish management goals, but **it went too far with too little information**. Controversy raged over the use level and phase-out issues during the next year and a half. The basis for the decisions was unclear, and they appeared final even though the Use Plan indicated the need for a "coordinated research program." In March of 1973, with the River Use Plan only 3 months old, the Department of the Interior issued a defensive statement that began "The decision which has been made regarding limitations on public use and motors on the Colorado River...was not made hastily and without taking into account all relevant factors." The document indicated that further information was needed regarding use levels and that several years would be required to collect it. The reduction of use was thus put on a conditional basis pending the outcome of research.

In regard to the motor-oar issue, however, the Interior document restated the apparently inflexible position presented in the River Use Plan: "motors are antithetical to the quality of a wilderness experience that is, and should be, obtainable in the Grand Canyon." It went on to evaluate the advantages of both oar and motor trips. The lack of air, water, and noise pollution were seen as advantages of oar trips, although "the environmental or sociological impact of such pollution" was not yet known. However, pollution was not the only issue. The Canyon was described as a "refuge from the pressure of modern life," a unique place in which one could "escape civilization." Oar travel was in keeping with the nature of the river-canyon "sanctuary."

The arguments in favor of motors fell into two categories—safety and convenience. Proponents of motor travel said that the greater size and power of their craft reduced danger in rapids, and that motor travel was easier, faster, and cheaper. The Interior document dismissed both contentions, but controversy over the motor-oar issue generally continued to form along these same lines. The point is that **the agency was using two different sets of "ground**

rules;" the use level issue would not be decided until research results were available, but the motor-oar issue had already been decided even though everyone acknowledged the need for more information.

There was one final but important point. Other regulations, such as those affecting trip departures or camp practices, were favorably received by most river runners. **No one seemed to contest the need to regulate or the agency's legitimacy to do so**; only the content of particular regulations was in question.

The river outfitters organized and filed a court suit, which they lost. They then increased their efforts at political and public pressure. The response of Park Service personnel was marked by hasty, inconsistent decision-making, and neither they nor the outfitters functioned at their best. Controversy centered on the motor phase-out issue.

An October 31, 1973, news release from Regional Director Howard Chapman said that the motor phase-out had been "deferred pending further study." At this point it appeared that both the motor-oar and use level issues would be researched. However, a December 10 letter to Senator Goldwater from acting Secretary of the Interior Whitaker indicated that studies would "in no way alter" the goal of wilderness classification for the River. This was supported by an April 2, 1974, letter from NPS Director Walker to Senator Steiger, which stated "the motors decision has already been made."

The outfitters continued to apply political pressure, maintaining their position that studies should form the basis for the motor-oar decision. This finally had an effect, and on June 3 Director Walker **reversed his earlier position**. He stated in a letter to Senator Jackson that studies would "provide a base" for river management decisions and that "existing river uses would...not be changed" until the study was completed.

Studies were conducted during the next 3 years. The sociological research centered on the carrying capacity and motor-oar issues. It is interesting to note that while the research was being designed and initiated, allocation of permit between private and commercial users had not yet become an issue because allotments allowed all the use that had occurred in 1972. However, allocation began to appear inequitable as applications for permits in the private sector exceeded the number available by a greater and greater margin. In the progress report for the first year pilot study it was pointed out that the growing private-commercial controversy had not been mentioned or funded in the original contract, and the study would not sample private trips or look at this issue. When outspoken private users learned of this and expressed their displeasure to the Park Service, the Agency decided to provide additional funds to address the problem. Allocation had now become an issue, and **pressure from an interest group prompted research**.

The sociological study report (Shelby and Nielsen 1976a, b, c, d) was submitted in June of 1976 and reports on the 28 other studies were received at about the same time. These included an economic analysis of outfitting businesses; a campsite inventory; a study of trails; ecological/biological studies of streamside flora and fauna, human waste disposal, fish, and water quality; and studies of hydrology and erosion. The Park Service summarized the findings and began integrating the results into a management plan.

A year and a half later, late in 1977, the Park Service issued a Draft River Management Plan and a Draft Environmental Statement (USDI 1977a, b). These documents included proposals for establishing a carrying capacity and limiting motor use which were finalized in a Final Environmental Statement in July 1979 (USDI 1979). The following information is drawn from all three documents.

What Was Decided?

The management plan first established the goals—"The goals for management of the Colorado River in Grand Canyon will be to perpetuate the wilderness river-running experience and to attempt to mitigate the influences of man's manipulation of the river" (USDI 1977a). The wilderness experience goal was supported by earlier documents including the 1971 Draft and 1975 Final Master Plans for the park, input from public meetings, two surveys of river users, and the judgment of managers. **The solidity of this goal was extremely important throughout the discussion and controversy** that surrounded the development of the management plan. Managers referred to it continually, explaining how proposed policies fit with the management goal. If someone questioned a policy, they had to either show why it didn't serve the goal or question the goal itself.

Use levels and carrying capacity

The management plan considered three different types of carrying capacities—ecological, physical, and social. **Ecological** studies showed that current use was causing changes that were a function of use patterns and activities rather than of overall use levels. One party using inappropriate camping techniques (e.g. for waste disposal) had a greater effect than many parties using lower impact methods. The solution was a set of prescriptions aimed more precisely at decreasing impact, including carryout of human waste, eliminating wood-gathering for fires, and establishing an education program to inform users of appropriate use practices. In the biological area, then, research showed that **an overall cutback in use was not necessary to achieve the desired ecological conditions**.

One of the alternatives considered in the decision process was to "increase visitor use level to the absolute **physical** capacity of the system." A physical carrying capacity based on a computer simulation model was worked out using data from the campsite inventory study. Assuming one party per beach and a 4- by 8-foot flat area for each person for sleeping, each site was evaluated in terms of the largest party it could accommodate. "Under a very tight scheduling system of launch days and times, campsite space assignment, structured river travel restrictions, time and area limitations at attraction sites, and a standardized trip length of 12 days, this alternative could ... (result in) ... an 85 percent increase in total visitors and a 242 percent increase in total user days" (USDI 1979).

The greatest impact of this alternative would be social. Standardizing trips would "significantly reduce options for trip variety and experiences." Strict scheduling would be required to reduce encounters among groups, and even then they would exceed current levels. Regimentation would also occur in other aspects of the trip. In sum, "regimentation, scheduling, and lack of options would detract from the quality of the visitor's experience" (USDI 1979). Research in this area showed that **the canyon was physically capable of holding more people, but no one seemed particularly interested in the necessary trade-offs**; the result wouldn't fit anybody's idea of a wilderness experience.

What about **social** capacity? The management plan described a wilderness experience in terms of close contact with the river-canyon environment without interference from other parties. Research had shown that use was concentrated in both space (popular attractions and camps) and time (heavy use days of the week and months of the year). The problem was to establish a number that would allow as many people as possible to use the resource without exceeding policy standards describing the desired experience.

The solution required a lowering of use at peak times. Although this might have been accomplished by decreasing seasonal use levels, a more efficient approach (Shelby and Nielsen 1976b) was to establish the daily launch limits that data showed would produce a contact level in line with most people's preferences (three or less encounters with other groups per day). It was then possible to lengthen the season so that this number of parties could leave on as many days as possible. Clear management objectives (reducing encounters) and research showing the connection of management alternatives (use levels) to visitor experience preferences (encounters) made it possible to plan for **a higher quality experience with a substantial increase in overall use**.

The plan also called for a 6-month summer season and a lower use winter season. Although the primary justification for the lower winter level was biological, it was also intended to "provide for a wilderness river trip where the likelihood of encountering other trips is remote" (USDI 1979). **Interactions between researchers and managers had helped both groups think more clearly about experiences, and the plan provided for two kinds of experiences with different encounter levels**, a first in river management.

Motors and oars

The "wilderness experience" goal was a major consideration in deciding the motor-oar issue. The plan defined the experience in terms of opportunities for relaxed conversation, interpretation, off-river hiking, a close relation with the natural environment, and meeting the river on its own terms. The problem was to determine the kind of trip that best met these management objectives.

Research results showed a number of structural differences between standard motor and oar trips (Shelby and Nielsen 1976d). Motor trips had more people, fewer boats and boatmen, more people per boat, and more contact with other parties than oar trips. People on motor trips also spent less time in the canyon and made fewer and shorter side trips than those on oar trips. But how did these differences affect passenger perceptions and experiences?

Experimental combination trips allowed passengers to travel half of the canyon on an oar-powered raft and the other half on a motor rig. After experiencing both kinds of trips, an overwhelming majority (80 to 90 percent) preferred oar travel (Shelby and Nielsen 1976d). Reasons given by passengers included the slower, more relaxed pace, the opportunity to experience natural sounds and water movement, and the smaller, more comfortable social groupings. People described motorized travel as speedy, hurried, rushed, noisy, loud, and crowded. By contrast, oar travel was described as leisurely, relaxing, peaceful, quiet, friendly, individualized, and intimate. The data, then, were fairly compelling; motor trips just didn't seem to fit with the Park Service's definition of a wilderness experience.

The Management Plan called for a phase-out of motorized travel. The data suggested that the conversion to rowing trips would lead to smaller parties, smaller boats, fewer people per boat, a lower passenger-guide ratio, longer trips with more stops at attraction sites, and quieter travel. The fast, short trip would be eliminated. **These differences would change the character of river trips to be "more consistent with a natural or wilderness experience,"** with greater opportunities for a close relation with the environment, relaxed social interaction, and interpretation by guides (USDI 1979). Data from other studies were used to show that the decision would have little impact on biological, economic, or safety factors and would reduce noise and water pollution.

The decision was fairly unique in river management. Biological and economic factors had been considered but did not show major differences in the impacts of motor versus oar trips, so the choice had been made primarily on the basis of social aspects of the visitor experience. But most importantly **the Agency had specified management goals and made a commitment to a "public" decision process; data were then gathered that helped clarify goals and showed how different alternatives fit with them**.

Interactive or Linear Decision Making?

To summarize, the case history for Grand Canyon shows a somewhat disorderly interactive decision process. The Park Service reacted to initial problems of crowding and conflict with decisions to greatly reduce use and phase out motors. Those decisions would have been controversial anyway, but their apparent arbitrariness in the absence of supporting data left them open to question. Strong political pressure from a variety of sources caused the Agency to back down until more complete information was available. Data were collected and as a result the use level decision was reversed and use limits were raised. The decision to phase out motors remained the same, but it was based on more specific management goals and solid information about which alternative best accomplished those goals.

POLITICAL FACTORS IN RESEARCH UTILIZATION

Political factors appear to play a major part in the way research is used. In this section, I would like to draw on the Grand Canyon case study to develop specific statements regarding the ways politics enter into the utilization process.

(1) **Determining policy direction is an interactive process, so management goals should be stated as early as possible; they can be more thoroughly developed as information becomes available**. In Grand Canyon the "wilderness experience" goal was suggested in 1971. Succeeding documents restated and clarified the goal as public reaction and research results provided more information. By the time final documents were written, the goal was clearly defined and well established. General goals are needed at the outset to determine the relevant areas for research and give the public information about what managers are thinking. And as data becomes available, managers will be more aware of possibilities and public sentiment. Grand Canyon data helped clarify objectives for carrying capacity as well as for travel modes.

Stating management goals will also help focus the interactive process. Critics can disagree with goals, giving managers a chance to reconsider and possibly modify their position. Critics may also agree with general goals but disagree with the action chosen to reach them. This may encourage managers to think of more effective policies or users to suggest alternatives of their own. Both cases are likely to create situations in which managers and users work together to come up with the best solution.

(2) **A single or lead agency will probably be more effective in developing policies than multiple agencies that require greater coordination**. The Park Service had primary responsibility in Grand Canyon; it had to contend with public controversy, but at least there wasn't another agency with a different mandate, conflicting traditions, and another set of managers. Even when the content of decisions was controversial, no one questioned the legitimacy of the agency to decide. The Rogue River in Oregon provides a contrasting example. The USDA Forest Service and Bureau of Land Management control the adjacent land, the State Marine Board has responsibility for rules governing use, two counties feel they should be involved, and people in the local area think of the Rogue as "their" river. Attempts to establish a lead agency have been only partially successful, so management decision-making requires an incredible amount of negotiation.

(3) **Decisions based on poor information won't hold up**. The early decisions to reduce use and eliminate motors in Grand Canyon are classic examples of managers going beyond their data and soon being forced to back down.

(4) **Agencies can establish the "ground rules" regarding the use of scientific data**. The Park Service did this unwittingly in the early stages at Grand Canyon by saying that carrying capacity decisions would take research results into account while the decision to phase out motors would not. Opponents of the motor phase-out argued that the same principle should be applied to the motor-oar issue. Outfitters as an interest group fell into the ironic position of bludgeoning a reluctant Park Service into a more extensive research effort. The same thing happened later when allocation became an issue and private users insisted that sociological research should be extended to include private trips.

(5) **Controversy may be liberating as well as nerve-wracking**. With highly political issues, **any** decision is likely to be questioned—probably in court. In Grand Canyon the outfitters threatened litigation if motors were banned, and the Sierra Club threatened the same if they weren't. Managers knew they would be questioned either way, and they appeared to set the controversy aside while they used their extensive base of research and public involvement to make the most defensible decision.

(6) **A good information base requires an investment of time and money**. The Colorado River Research Program for Grand Canyon took 3 years of intensive work on 29 different studies at a cost of about $750,000. Areas that lack the national prominence of a place like Grand Canyon obviously cannot afford and may not need this kind of investment, but this often is used as an excuse for limited data, poor quality information, and "shoot from the hip" decisions. If policies are questioned, the investment in good information may save a great deal of time and money that would otherwise be spent defending and backtracking. An on-going monitoring program may also be necessary.

(7) **Research may serve purposes other than information-gathering**. The research program in Grand Canyon "bought" 3 years of time to stabilize use under an interim management plan. This gave everyone a chance to define the issues and think about and experiment with solutions in a more relaxed atmosphere in which new ideas were less threatening. The issues were complex and all parties had a chance to become "educated."

(8) **Research may suggest less controversial solutions in which "everyone wins."** The carrying capacity issue in Grand Canyon is a good example. Lowered daily launch limits made encounters less likely, but lengthening the season meant overall use was increased and no user group faced a major cut-back.

(9) **A controversial issue may create some "breathing room" for making decisions about another less controversial one.** Arguments about motor travel in Grand Canyon have in many ways overshadowed the carrying capacity decision, resulting in less discussion about what might otherwise have been a hotly contested issue. It would be hard to design this kind of situation but perhaps easy to take advantage once it was recognized.

(10) **Social science research results supported the views of less vocal groups, so research results may be attacked by more vocal groups.** Grand Canyon data from public meetings and user surveys showed that most people supported the "wilderness experience" goal, but these findings were questioned by some outfitters whose views had previously carried greater weight. Similarly, outfitters running motorized trips were quick to contest results from the motor-oar experiment that showed user preferences for oar travel.

(11) **Dialogue between managers and researchers is essential.** Meetings with Park Service personnel and an annual Grand Canyon Research Symposium provided a number of opportunities for

esearchers to report preliminary findings. This enouraged them to organize their thoughts and alowed managers and others to see patterns emerge. All groups had numerous opportunities to identify nanticipated problems and take corrective action, nd managers were able to learn about issues along with researchers. The final research reports conained more details but no major surprises. Work with allocation systems in Hells Canyon presents a ontrast. After the project was begun, we worked for more than a year with only a few meetings with Forest Service personnel. When we submitted a draft f our final report, the Forest Services's reaction was urprise mixed with chagrin. They were counting on pecific recommendations that we had consciously voided. In several subsequent meetings we negotited the issue and agreed to add a section to the final eport. The problem was solved, but it should never ave arisen in the first place.

CONCLUSION

Researchers and policy-makers work in different worlds. They have different roles that are separated y the demands of day-to-day tasks and the time and istance that make it hard to get together. Engaging n purely theoretical research maintains the separaion. But research application creates an area of verlap in which each group has to learn something bout the other; cooperation is needed to get high uality information and use it effectively. From a cientist's point of view, this means recognizing the nteractive nature of the policy world and undertanding the ways that politics affect research utiliation.

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BACKCOUNTRY MANAGERS NEED SOCIAL SCIENCE INFORMATION

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Backcountry or wilderness portions of the National Park System provide unique opportunities for solitude encounters with nature. Backcountry managers must be sensitive to this wilderness character as they manage these areas to "preserve and allow for enjoyment." As use of these areas increases and impacts on the resources and experience increases, the manager often will need to set a limit or carrying capacity. To give direction to carrying capacity deliberations, management objectives must be established. Carrying capacity for backcountry has three basic limits —physical, biological, and social. Of the three, the social limits are the most difficult to set and are usually the most restrictive. The social capacity looks into the nature of the experience itself and considers such things as number and types of encounters, group sizes, kinds of activities, modes of travel, visitor perceptions as to quality of experience, etc. This kind of information was valuable in setting a capacity for river running use at Grand Canyon. This information was provided by social scientists and is best used to set and evaluate social capacity limits for achieving specific management objectives. Decisions are not directly derived from research; many other factors must be considered. These are not the traditional tools of park managers but are essential to respond to the current and rapid growth in backcountry use. Failure to set capacities is a management action that will profoundly affect visitor experience. Information from the social scientists is critical to setting social capacities for backcountry or wilderness areas of the National Park System so that those areas will provide the opportunity for high quality visitor experience.

WILDERNESS IN NATIONAL PARKS

Within the National Park System, many areas of natural backcountry remain in an undisturbed condition. Some of these areas are extensive, contain unique features, and provide outstanding recreational opportunities. Although few Park System units are designated wilderness, many of them fit the definition of wilderness. Some areas have been proposed for addition to the wilderness system and most are being managed as though they were wilderness For the purpose of this paper, backcountry will be considered as synonomous with wilderness.

The purpose of the National Park Service is to manage all areas within the System—"to conserve the scenery and the natural and historical objects and the wildlife...and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations." This is an oft repeated phrase within the National Park Service, but, is the very heart of its existence. The phrase translates into a variety of management actions for the wide variety of park areas. For the backcountry manager of park areas this phrase may be more critical than to most other park managers. The backcountry manager has a portion of the natural setting within a national park or monument that by its very nature must remain the least impaired of any and perhaps provide the most in-depth, profound, and extensive of all park experiences.

Recreational use of backcountry areas within the Park System has skyrocketed in the past decade. A classic example of increase in backcountry use is that of whitewater river running. On the Colorado River within Grand Canyon, river running use increased from 2,099 people in 1967 to 16,432 in 1972. On the Colorado River, in Cataract Canyon within Canyonlands National Park, use increased from 585 people in 1969 to 4,422 in 1973. In Dinosaur National Monument on the Green and Yampa Rivers, the number of river runners increased from 2,493 in 1967 to 16,739 in 1973. In all of the above situations managers observed very rapid deterioration of riparian ecosystems of these rivers. Trash and litter became significant problems. Human waste disposal became a critical problem and multiple trailing at attraction areas along the rivers became a serious impact. In addition to these very obvious and recognizable impacts, managers began to receive reports from river runners voicing dissatisfaction with the river running experience, particularly noting crowding at attraction sites and popular camp areas. This dramatic increase in use and the related problems that surfaced are not unique to river running. In almost all park areas that have backcountry hiking opportunities the same scenario was repeated during the same approximate time. Concern over these mounting problems has been expressed by many managers, backcountry users, conservationists, etc. This situation was also common in backcountry areas managed by Forest Service, and Bureau of Land Management during recent years.

CARRYING CAPACITY

As managers began to react to these problems they found that some research work had been done in regard to capacities for backcountry or wilderness areas. One of the solutions recognized by managers and suggested by researchers was to establish a carrying capacity for the backcountry or wilderness area in question. In establishing a capacity for a given area the manager must recognize many variables that will affect his particular situation. The overriding and most important of all considerations that the manager must keep in mind is the **management objective** for the area. This objective will likely have been established and articulated in a general management plan for the park. If not, this objective is the first task of the manager and will include consideration of the legislation establishing the park area, data on park ecosystems and current use, as well as public input. Once objectives have been established, the manager can proceed to develop data that will aid in making a decision on carrying capacity. Capacity is generally a function of the physical, biological, and in recent years, social limits of a given backcountry system. Experience during the past few years indicates that the physical capacity can be readily assessed by conducting an inventory of the access system (roads, trails, and rivers) and available campsites within a backcountry. The biological capacity can be developed by assessing the kind and magnitude of impacts that will be imposed upon a system if used at full physical capacity.

The social carrying capacity of a backcountry area is much more elusive than either the physical or biological capacities. The social capacity relates largely to the quality of experience available for the visitor to a backcountry area. This is a function of (1) number of people, (2) group size, (3) length of stay, (4) method of travel (hiking, boating by motor or paddle or rowing boats), (5) number and kind of encounters among groups or individuals, (6) type of activities (boating, hiking, climbing, camping, fishing, etc.).

EXPERIENCE AT GRAND CANYON

Experience at Grand Canyon during the past few years with both river running and backcountry hiking indicates that the biological capacity of a system will normally be more restrictive than the physical capacity. And the social capacity will be more restrictive than either the physical or biological limits.

In working toward a physical capacity for the Colorado River, the most limiting physical factor was campsite availability. Studies indicated that only 25 to 30 percent of the beaches were being used. Research data indicated that the physical capacity could be tripled, but rigid scheduling of trips would be necessary, compromising the quality of experience.

In establishing a biological capacity, no direct correlation between number of people and environmental damage could be established. In fact, setting specific **requirements** on the existing number of river runners was sufficient to protect the riparian and side canyon areas of the canyon from unacceptable impact and thereby be within the biological carrying capacity of the system. Therefore, it can be said that **patterns of visitor use are more important biologically than are number of people** (Carothers and Aitchison 1976). The variety of requirements used to control visitor use patterns that have proven successful include hauling out human waste, hauling out all trash and litter, using fire pans, hauling out all ash and charcoal from fires, building fires only during certain times of year to conserve firewood supplies, constructing single trails at attraction sites, and straining all liquid kitchen wastes.

Physical and biological capacities of the river riparian ecosystem on the Colorado River within Grand Canyon were easy to establish compared to the sociological capacity, which more directly affects the quality of experience. The mode of travel (motor or oar powered); ratio of commercial passengers and noncommercial river runners; and congestion, crowding, and contact factors were much more difficult to determine. Data gathered by sociologists provided information for river managers at Grand Canyon that were useful in establishing the sociological capacity (Shelby and Nielsen 1976a, b, c, d). Findings that proved to be most useful for forming a basis for these decisions included:

- Existing levels of encounters between groups, as well as visitor preferences on levels and type of encounters.
- Relation between visitor satisfaction and levels of encounters, wilderness character of the trip, and contacts and crowding.
- Visitor perceptions and preferences regarding motorboat and oar boat travel.
- Demographic characteristics of motorboat and oarboat visitors and commercial and noncommercial river runners.

In considering the social capacity of a backcountry area it is necessary to refer to management goals for that area and determine the amount and timing of use that would produce the desired level of encounters.

Research can provide information to the manager as to how well an existing or proposed management system will achieve established objectives but it cannot be used to establish objectives. Research data on physical, biological, and social limits on river running at Grand Canyon were valuable in developing a carrying capacity for the river system. However, continued research monitoring will be essential to evaluate the management plan and either validate the decisions made or indicate needed changes. A major failing of managers is to research a particularly difficult problem on a one-time basis with no follow up monitoring of the decisions made. In fact, research is **most** useful to backcountry managers when it is used to evaluate the success of a management system. It is important to emphasize that decisions are not converted directly from research data to management policy. The manager must play the sociological research data against the objectives for management of the area as well as physical and biological data and public input. Referring again to the river management situation at Grand Canyon, data on current use levels related to contacts and crowding were useful in setting use capacities. However, to make a decision it was necessary to consider the variation in skill levels between commercial and noncommercial river runners to follow resource protection procedures, shift in type of boats from motor to oar, change in trip length, economic viability of concessionaires, and public and political input.

TRADITIONAL MANAGEMENT TOOLS

The traditional management method used by the National Park Service was to set limits on the basis of the location of roads and trails, number and size of campgrounds or recreational vehicle parks, and amount of motel or hotel accommodations available. The aggregate of such facilities establishes an overall capacity for a given segment of a park. An example in which this method was used is for the South Rim Village of the Grand Canyon. There is a specific number and distance of roads and trails, that will daily accommodate a certain number of vehicles and people. There are a certain number of hotel or motel rooms, and a specific number of campground, picnic, and recreational vehicle sites. Therefore, only so many people can reasonably gain access to the South Rim Village each day. The density of visitors directly affect the quality of experience that is to be provided for the park visitor. The management objectives for the South Rim Village are to provide a high density, developed type of experience. Therefore, these management methods are appropriate. For backcountry areas, these management methods are not appropriate and managers must find other ways to meet the objectives.

INACTION IS A FORM OF MANAGEMENT

The type of experience to be provided for the visitor is controlled as much by what we do not do in terms of management as by what we do. If we do not set limits for the concessionaire or the do-it-yourselfer, they will set their own and the quality of experience will be affected accordingly.

KINDS OF INFORMATION NEEDED

In a backcountry or wilderness situation the level of contacts or crowding must be more closely scrutinized because the visitor to this type of area is usually much more sensitive to contacts than a developed area visitor. Therefore, the manager must consider how many people or groups can be allowed in a given part of the backcountry on a given day, week, month, or season. This is necessary so that contacts between people and or groups are kept at a level that maintains the quality of backcountry experience at an acceptable level. What that acceptable level may be will vary from area to area. Therefore, the manager must have data on what the general visitor's perceptions of appropriate crowding and contact levels are for a given area. The manager also needs information on existing levels of use, crowding, and congestion as well as on demographic characteristics of the visitors. With this kind of basic data the manager can begin to make reasonable decisions on use and management of backcountry areas of the National Park System.

SITE SPECIFIC DATA NEEDED FROM SOCIAL SCIENCES

Much sociological data on backcountry use and users can be applied generally from one area to another. However, it is essential that a manager closely scrutinize such data before applying it to another area. In most instances, it will be best to also develop site-specific information. Most importantly, it is imperative that a manager set up a monitoring program on social interactions of backcountry users to test the continued validity of any decisions that are made from data provided from initial research on the specific situation or borrowed from another area. This kind of information can best be provided from the social sciences.

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PUTTING RIVER RESEARCH TO WORK: A CARRYING CAPACITY STRATEGY

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A major problem in determining recreation carrying capacity for large wildland areas has been a lack of research data (Burch 1974). An effort was made to rectify this deficiency at Ozark National Scenic Riverways (ONSR) in southern Missouri by designing a research program in 1972 (Chilman *et al.* 1977). This multifaceted program was implemented from 1972 to 1977. The question then became how to put the research results to use in a management decision process that included public involvement.

The first step was to make the research results accessible and open to evaluation. This was accomplished by publishing a report that summarized the rationale, methods, and results of the various recreation carrying capacity research projects (Marnell *et al.* 1978). These projects included studies of canoeist numbers, site impacts, water quality, safety factors, and visitor characteristics and perceptions. More than 500 copies of this summary report were distributed prior to public hearings in September 1979 so that the public would have an understanding of the information base developed by the National Park Service for this decision situation.

The next step was to derive a descriptive model of management decisionmaking steps related to recreation carrying capacity concepts. This model was needed because of confusion about how the ONSR river research data related to various aspects of recreation carrying capacity decisionmaking. The model was derived from a review of the recreation carrying capacity literature, as related to the experience with carrying capacity decisionmaking at ONSR and in other field locations (U. S. Department of the Interior 1977).

THE DECISION SITUATION

Ozark National Scenic Riverways is a large and complex river recreation area. It encompasses 140 miles of land corridor along the Current and Jacks Fork Rivers in southeastern Missouri. The attractions of Ozark Mountain scenery and clear, free-flowing rivers coupled with relative safety of floating have made ONSR a popular recreation attraction.

The canoe floating use of ONSR has increased an average of 10 to 15 percent annually since it was established as a National Park Service management unit in 1964. The number of floater days has increased from an estimated 40,000 in 1968 to more than 242,000 in 1977 (Marnell *et al.* 1978). A straight-line projection of 10 percent annual increases would more than double the 1977 number to 515,000 by 1985. Questions began to be raised about how much canoe use could be sustained without seriously impairing either the ONSR environments or the recreation experiences of visitors (Jackson 1970).

The approach to dealing with the increased river se centered around a river use research program ecommended in 1972 (Chilman *et al.* 1977). The pproach (1) utilized an integrated research pro- ram, (2) recognized the need for several years to nplement the program, (3) recognized that several esearch disciplines would be involved, and (4) uti- zed recreation carrying capacity as an integrating ncept for considering the diverse factors involved.

Because ONSR is administered by the National ark Service as a National Recreation Area, a parity etween human and environmental considerations as needed in setting research priorities. In terms of udget and manpower expenditures, these two broad onsiderations received approximately equal atten- on (Marnell *et al.* 1978). All problems attending iver floating use of ONSR could not be addressed at nce. Therefore, priorities were set on the basis of two riteria: (1) investigative efforts had to produce eaningful data within imposed time and fiscal onstraints, and (2) some prospect, both practical and olitical, had to exist for relieving some of the pres- ures on the National Park Service management. he program was also designed with the assumption hat additional research would follow to compensate or short-term deficiencies (for example, more long- erm studies are needed on the status of various rare r endangered wildlife species).

An important factor associated with the recreation arrying capacity decision strategy at ONSR was the ime frame involved. Recognizing the need for sev- ral years to implement the research program al- owed for in-depth thought about recreation carrying apacity concepts and rationale as well as for collect- ng research data. In many previous situations in hich field managers looked to recreation carrying apacity for relief from problem situations, immedi- te or short-term solutions were demanded. In these ituations, no time was allowed to study the complex nvironmental and social factors involved in carry- ng capacity determinations.

The research program time frame at ONSR was nstituted in the form of a 5-year management mora- orium on increases in numbers of canoes allowed to e rented by concessionaires. This attempt to pre- erve the status quo did not succeed in holding river se at 1972 levels (canoe use increased on other than eak weekend days and from canoes brought in by ther than licensed concessionaires). However, it did rovide time for more structured carrying capacity ecisionmaking.

In retrospect, no more of a crisis exists at ONSR currently than existed in 1972. This suggests that thinking about a solution to management problems of a complex carrying capacity nature might usefully be replaced by a concept of a "program of actions." We should think about carrying capacity as more than a calculation and also be able to visualize what actions are necessary before and after the calculation step to make decisions about recreation carrying capacity.

THE ONSR RECREATION CARRYING CAPACITY PROCESS

After the research program was completed, the next step was to develop a conceptual framework to indicate how the recreation carrying capacity research results related to the process of recreation carrying capacity decisionmaking. The following conceptual framework is patterned after the notion of a "planning process" as a technique used by planners to indicate or display "an organized sequence of steps requiring conscious and continuous action" (Uleck 1971). This planning process frequently takes the form of a chart displaying a sequence of steps to indicate where activity is occurring and how it is related to other considerations.

Because recreation carrying capacity was chosen as a conscious strategy at ONSR, the following sequence of steps was developed from a review of the recreation carrying capacity literature in relation to actions undertaken at ONSR since 1972. The nine-step process is outlined and each step is then briefly discussed.

These steps should not be considered as mutually exclusive, but as more or less sequential and focused on keeping in mind preceding and succeeding steps. For example, the ONSR Recreation Carrying Capacity Decisionmaking (RCCD) process is now focused on Step 5 (Public Review) but with Steps 3, 4, 6, and 7 also currently a part of decision considerations.

Step 1. RCCD Initiated by an "Unacceptable Change" in the ONSR Situation.

A major responsibility of a recreation area manager is to recognize and deal with changes in the recreation management situation (Gould 1968). This is recognized in the Lime and Stankey (1971) definition of recreation carrying capacity: "the amount and type of use an area can sustain over a specified time period without causing unacceptable change to the physical environment or to the experience of the user." It is important to keep in mind that changes are constantly occurring in physical, biological, social, or organizational factors related to large wildland areas. The key word is "unacceptable." Often that condition is arrived at incrementally (as with increasing use) or is subtle and difficult to detect (water quality changes or visitor perceptions of crowding).

The need is to identify as clearly as possible the nature and rate of change that is triggering carrying capacity decisionmaking. At ONSR, the increasing number of canoeists was highly visible to managers and repeat visitors, and the rate of increase was indicated by annual use estimates. Specific media articles began to call public attention to these increases (Jackson 1970).

Step 2. Specific Areas Affected by Change Need Identification and Study.

The area or areas affected by the "unacceptable" changes must be identified in relation to management unit boundaries and area features. Large wildland areas, such as the 140-mile ONSR land corridor, may need to be divided into subunits, or zones, for recreation carrying capacity studies.

Maps of ONSR were used to study the increasing canoe use phenomenon in relation to access roads, traffic flows, attraction points, etc. Available information on ecological characteristics, visitor use, and management authorities and guidelines were examined.

Step 3. Research Measurements of Change Factors and Trends Instituted.

Information is often lacking in aspects relating to specific changes occurring at specific places. How many visitors are using a specific area? What is the nature of the recreation experiences they are seeking? What are the unique attractions of the area for visitors? What conflicts are occurring, and where? What specific site impacts are occurring; and at what rate? Are special features, i.e., archaelogical sites, subject to damage?

These and many other questions require specific data for decisionmaking, especially when such decisions may be subject to legal challenges. New research approaches, i.e., use of time-lapse photography for canoe counts, had to be devised to meet research needs at ONSR (Marnell *et al.* 1978). The notions of (1) designing a field unit research program to gather and integrate various data needed, and (2) developing research capacities in a field unit to direct and interpret research for management decisionmaking were part of the research considerations at ONSR (Chilman *et al.* 1977).

Step 4. ONSR Recreation Opportunities Compared to Others in Surrounding Region.

The concept of providing a spectrum of recreation opportunities for diverse types of visitors is basic to recreation carrying capacity thinking (Wagar 1966, Nash 1968, Lime 1976). Wagar (1974) emphasizes: "Examining one area at a time may be the trap that has caused so much confusion about use limits for specific areas. The crucial question becomes: what management pattern, including kinds and amounts of use, will permit this recreation area to make its maximum contribution to the sustained benefit provided by the whole system of recreation areas?"

Our experience at ONSR was that specific knowledge of the area gained in Steps 2 and 3 enabled more systematic comparisons with other recreation opportunities in the region. In particular, data were collected in 1979 on visitors' perceptions of ONSR in comparison to the Eleven Point and Buffalo Rivers and other federally administered riverways in the Ozark Mountains region. The focus is on determining unique, or differentiating, factors in river recreation to be maintained as a wider range of choice in a spectrum of recreation opportunities.

Step 5. Public Inputs and Review Toward Capacity Decision Values Consensus.

Wagar (1974) has noted: "even if research can show how areas and experiences will change with various levels of use and various management practices, someone must still decide what changes are acceptable." One of the most significant changes in resource management decisionmaking in recent years is that public review be part of the process. This does not take decisionmaking from managers, but it does ensure more systematic information-gathering and presentation.

Public agencies appear to be adapting to utilizing a variety of techniques to gain public involvement. At ONSR, the most visible manifestation of public involvement has been the scheduling of two sets of public hearings conducted at five different locations in Missouri and Illinois. The first round of hearings was conducted in September 1979 to solicit comments on management problems as perceived by visitors and others interested in ONSR. A second round of hearings was conducted in February 1980 to seek comments on alternative proposals for dealing with entified problems. The hearings are conducted ntly by National Park Service planners from the nver Service Center and by the ONSR Superin- ndent and his staff.

ep 6. Carrying Capacity Calculated.

After the area and region have been studied and e public has been involved, the carrying capacity n be calculated. Various writers have noted the ntral relation of area management objectives and propriate recreation carrying capacities (Wagar 64, Lime and Stankey 1971). Brown *et al.* (1976) dicate that the definition (or redefinition) of man- ement objectives for an area and the calculation of ecreation use level consistent with those objectives ke place at the same step in the process.

A recent example of a recreation carrying capacity lculation for a wildland river area is the draft of the lorado River management plan (U.S. Department the Interior 1977).

ep 7. Management Techniques Selected to Implement the Objective.

Calculating a desired carrying capacity is only part recreation management decisionmaking. Imple- entation of desired capacity conditions depends on owledge of a wide variety of management tech- ques (Lime 1976).

In most recreation management situations a vari- y of techniques will be applied to deal with various cets of desired conditions. For example, at ONSR a ajor concern has focused on the need to utilize a noe use permit system to maintain "quality." ther techniques, i.e., trail development and rein- rcement at Pulltite Spring, will also be used.

ep 8. Problems of Technique Implementation Must be Studied and Discussed.

Managers need to keep in mind that problems nstantly arise during implementation of manage- ent techniques. Simply selecting a technique is ly part of the job. Questions immediately arise out costs, additional personnel, training, etc. But, ore basic are questions of legality. The Lake ounty Circuit Court ruled that the Michigan De- rtment of Natural Resources did not have author- y to enforce regulations devised to deal with in- easing canoe use in Michigan (Doehne 1977).

When management techniques are initiated, some sers may seek ways to "beat the system," especially r various types of permit systems. Managers need to be constantly alert and exchanging information with other managers on effective implementation of management techniques.

Additionally, effects of various techniques applied on a particular area need to be considered in light of their effects on uses of other areas. Exclusion of particular uses or activities may mean they will shift to other areas where they may be even less desirable. For example, shifting some of the high density canoe use on the upper Current River at ONSR to the lower Current River may adversely affect Ozark johnboat fishermen (Marnell *et al.* 1978).

Incorporating these considerations into recreation carrying capacity thinking is indicated in Wagar's (1974) systems perspective—"How can the management of this area be coordinated with that of other areas?"

Step 9. Initiate a Monitoring Program to Measure Future Area Changes

With this step, we come full cycle to the manager's continuing responsibility to recognize and deal with changes. Along with studies to understand baseline characteristics of a recreation use situation, trend data on rates of change are important.

From studies to determine baseline characteristics, some of the aspects of ecological and visitor use conditions are selected for repeated measurements. Those measurements are programmed into a system of monitoring measurements to be repeated at selected intervals. Continuing efforts must be made to develop new types of measurements for monitoring purposes and to refine the measurements for improved effectiveness and for reducing data collection costs. For example, canoeists' perceptions of crowded conditions on ONSR were measured in 1972 and remeasured in 1977 and 1979 as a form of monitoring changes in perceived recreation quality (Chilman 1979). The two remeasurements were done in conjunction with other ONSR visitor studies as a means to keep costs down.

Beyond acquiring baseline and monitoring data, methods to organize and analyze these data and to interpret their meaning to decision participants may necessitate new types of organizational capabilities and training of personnel. This may be one of the most far-reaching implications of attempting to utilize research in recreation carrying capacity decisionmaking.

CONCLUDING REMARKS

Recreation carrying capacity was chosen as an integrating concept for researching the phenomena of increasing canoe use at Ozark National Scenic Riverways in southern Missouri. In addition to utilizing recreation carrying capacity concepts for research design, two innovations were developed to increase the effectiveness of the research. First, a river research summary report was widely distributed to improve decision participants' access to knowledge of the alternatives being considered. Second, a sequence of steps in recreation carrying capacity decisionmaking was identified and elaborated. Decision participants could then maintain an overview of various decision steps involved as they focused on utilization of research information at any particular step.

The opportunity has been unique at ONSR to work through this research-oriented sequence in conjunction with experienced researchers and concerned management staff. Our understanding of recreation carrying capacity decisionmaking has been developed in a situation with classic pressures of rapidly increasing recreation use and strong possibilities of lawsuits if use limits are established. Intensive interaction between researchers, managers, and planners was very important in our formulation of the nine-step process.

We believe that the strategy of identifying and arranging major components of recreation carrying capacity decisionmaking in "planning process" form helps to visualize and relate why we are doing what we are doing as well as what we are doing in utilizing research results at ONSR. The outlined process facilitates discussion and interaction among a variety of recreation carrying capacity decision participants in the ONSR situation.

We propose this recreation carrying capacity process model as a better way to examine important elements in recreation management decisionmaking. We now seek your comments and questions about the usefulness of this proposed model.

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KEY WORDS: trend analysis, quality recreation experiences, research application.

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FOREWORD

The Minnesota Forest Resource Inventory Conferences were held in Grand Rapids on May 14, 1980 and in White Bear Lake on May 16, 1980. The Conferences were conceived and sponsored jointly by the North Central Forest Experiment Station; Minnesota Department of Natural Resources, Division of Forestry; and the University of Minnesota, College of Forestry as a means of promoting useful dialogue within and beyond the Minnesota forestry community.

The purpose of the conferences was to inform the interested public of the background and results of the 1977 inventory of Minnesota's forest resources, and to make them aware of ways inventory information is utilized by the many kinds of users. To do this, we assembled speakers who were most closely associated with conducting the inventory, along with representatives of the key groups that make use of inventory data--forest industry, regional planning organizations, National Forests, State departments of natural resources, universities, environmental groups, and consultants. Their comments are summarized in the papers in this Proceedings.

Papers from authors outside the North Central Forest Experiment Station are printed just as received; their content and presentation are the responsibility of the authors themselves.

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OVERVIEW OF INVENTORY RESPONSIBILITIES

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Inventories of the Nation's forests date back to the early 1930's. Enabling legislation for the early inventories was the Mc Sweeney-Mc Nary Forest Research Act of 1928. For forty years this act provided authorization for our forest inventories. In 1974 new legislation amended the Mc Sweeney-Mc Nary Act and provided more comprehensive guidelines for National resource inventories. This new legislation was the Forest and Rangeland Renewable Resources Planning Act (R.P.A). It directed the Secretary of Agriculture to prepare a renewable resources assessment in 1975, and to update the assessment in 1980 and each 10th year thereafter.

The 1980 National assessment will soon be released. It provides four basic kinds of information: (1) a description of the resource base, (2) projected trends in supplies and demand, (3) economic, social and environmental impacts of these trends; and (4) opportunities to improve the trends that may have adverse impacts.

Timber resource information used in these National assessments is gathered by resources evaluation projects of the U. S. D. A. Forest Service (formerly called "forest survey" projects). They are located at six forest experiment stations across the country--Broomall, Pennsylvania; Asheville, North Carolina; New Orleans, Louisiana; Ogden, Utah, Portland, Oregon; and St. Paul, Minnesota.

The resources evaluation project for the North Central region is located at the North Central Forest Experiment Station in St. Paul, Minnesota and is responsible for inventorying resources in Minnesota, Wisconsin, Michigan, Iowa, Indiana, Illinois, Missouri, North Dakota, eastern South Dakota, Nebraska, and Kansas. The North Central Region encompasses the third largest land area in the Nation and has the fourth largest commercial forest land base. Although its softwood volume is small, its hardwood volume is second only to that found in the Northeastern region.

The fourth inventory of Minnesota was the most intensive Statewide inventory ever conducted in the United States. The Minnesota State Legislature provided the Minnesota Department of Natural Resources (DNR) with funds sufficient to triple the sample over that of the standard inventory. This was done because the DNR and other interested parties wanted more accurate county estimates than the standard inventory, authorized by Congress, would yield. The standard inventory would have provided reliable resource statistics, but only at the State level and for some of the larger, more heavily forested counties.

This intensified inventory of the State's forest land significantly reduced the sampling error of the resulting statistics. For example, the sampling error for the estimate of commercial forest land for 10,000 acres in the Northern Pine Unit was reduced from ± 30 percent (for a standard inventory) to ± 17.3 percent (for the intensified sample). If we assume that the 10,000 acres support 11 cords per acre of growing-stock trees (the average for this Unit) the sampling error for total volume is ± 26.5 percent for the intensified inventory. This is much less than the sampling error of ± 53.5 percent that would have resulted from a standard inventory.

The Minnesota inventory was a cooperative effort. Most of the aerial photos were provided by the Minnesota DNR. Other photos were supplied by county land commissioners, the two National Forests, and the Bureau of Indian Affairs. Agricultural Stabilization and Conservation Service photography was also used. The two National Forests provided resource information for their land. DNR foresters contacted wood-using plants in the State to determine the kinds and amounts of products coming from Minnesota's forests and also established two thirds of the field plots throughout the State.

North Central foresters established one third of the field plots required for the inventory and conducted timber utilization studies on current logging operations. These utilization studies provided the information necessary to link production figures provided by forest industry back to the amount of standing timber harvested to provide those products. Fieldwork began in July 1974 and was completed in March of 1978. Nearly 115 staff years went into the fieldwork for this inventory.

Another cooperator, the Minnesota State Planning Agency, developed a computerized vegetation cover type map of the State. North Central Station photo-interpreters delineated the various land classes on orthophoto maps, which were then processed into the type map by the State Planning Agency. As far as I know the resulting vegetation map is another first-of-a-kind.

Data processing was done at the North Central Station. Field plot sheets were sent to St. Paul where they were key-punched and edited. When an inventory unit was complete, area, volume, and growth statistics were computed and tabled. The Station has more than 7000 Minnesota statistical tables stored on microfilm--slightly more than 80 tables per county.

The information produced from the inventory is used by various groups for various purposes. At the North Central Station, resource analysts use the information to describe and highlight various aspects of the timber resource, point out areas of concern, and suggest possible alternatives.

Seventeen reports are planned by the Station to present Minnesota's forest resources:

Research Notes:

- Forest area in Minnesota
- Timber volume in Minnesota
- Minnesota land ownership trends, 1962-1977
- Biomass in Minnesota's forests

Resource Bulletins:

- Forest statistics for Minnesota, 1977
- Timber resource of Minnesota's Aspen-Birch Unit
- Timber resource of Minnesota's Northern Pine Unit
- Timber resource of Minnesota's Central Hardwood Unit
- Timber resource of Minnesota's Prairie Unit
- The fourth Minnesota forest inventory: area
- The fourth Minnesota forest inventory: volume, growth, removals, and projections
- Predicted yields from selected cutting prescriptions in northern Minnesota
- Treatment opportunities for current Minnesota forest conditions
- Operability of Minnesota's commercial forest lands
- Fuelwood production in rural Minnesota, 1975
- Minnesota logging utilization factors, 1975-1976-development, use, implications
- Biomass in Minnesota's forests

MINNESOTA FOREST INVENTORY PROCEDURES

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The inventory of Minnesota utilized a two-stage sampling technique. This approach uses aerial photography in combination with data obtained from on-the-ground measurements.

Aerial Photograph Sampling

The first step in the aerial photo sample procedure is to assemble a township mosaic of conventional aerial photographs. Next, a grid to match the township is placed over the photos. The grid is a transparent acetate sheet covering an area of 6 square miles in the scale of the photos used and is designed to locate 121 circular points, with each point representing 1-acre. This grid provides 100 percent area control when every township is counted. All points on the grid are then classified as to their land-use. These classified points give us a preliminary estimate of forest and nonforest land in a county. In Minnesota 72,700 points were classed as forest, 2,000 as questionable, 4,500 as unproductive forest land and 200,000 as nonforest or water.

Next, a photograph is taken of the township mosaic with the grid in place. This photo provides us with a record of all sample points and is insurance in the event we should ever lose track of the aerial photo used in the ground sample.

The township mosaic is then dissassembled and all forest points on the photos are stereoscopically interpreted. Each of the 72, 700 forest points in Minnesota were given 1 of 12 forest cover type classes.

The last step in the photo work phase is to systematically select a subsample of these photo points for examination on the ground to correct the preliminary area estimate for classification errors and for actual land use change since the photos were taken. In Minnesota, 9,800 points classed as forest, 4,500 points classed as unproductive forest, and 2,000 points classed as questionable were examined on the ground.

Field Data Collection

Of the 16,300 plots examined on the ground for the Minnesota survey, 8,547 were classed as commercial forest land. The ground sample phase of the inventory concentrated primarily on commercial forest land. However, limited ground data are collected on other ground land use classifications--unproductive forest land, productive reserved forest land, and nonforest land with trees such as wooded strips, and wooded pasture.

All the counties within a particular unit have similar tree species, forest types, etc. (figure 1).

The commercial forest land plots by Inventory Unit were as follows:

	Number of plots
Aspen-Birch Unit	3,093
Northern Pine Unit	3,718
Central Hardwood Unit	1,362
Prairie Unit	374
Total	8,547

Tree measurements were made on the 8,547 ground plots plus the data from the National Forests are the basis for estimates of timber volume, growth, mortality, number of trees, and other forest classifications. Each ground plot represents about 1,400 acres of commercial forest land.

The first step in locating the forest sample location is to draw a straight reference line between two features visible on the photograph and eaily located on the ground. A good example of such a feature is a straight road section. This reference line with azimuth is recorded on the back of the aerial photograph.

Next, a starting point is selected. It has to be a landmark readily identifiable on the ground and on the photograph and as close to the sample location as possible. Landmarks are selected that can be easily identified later for remeasurement purposes, for example, a prominent tree along a road.

Using the reference line and a line from the starting point to the ground plot on the aerial photograph, an azimuth and distance are computed from the starting point to the ground plot location. Then a course is run from starting point to plot center using compass and 100-foot tape.

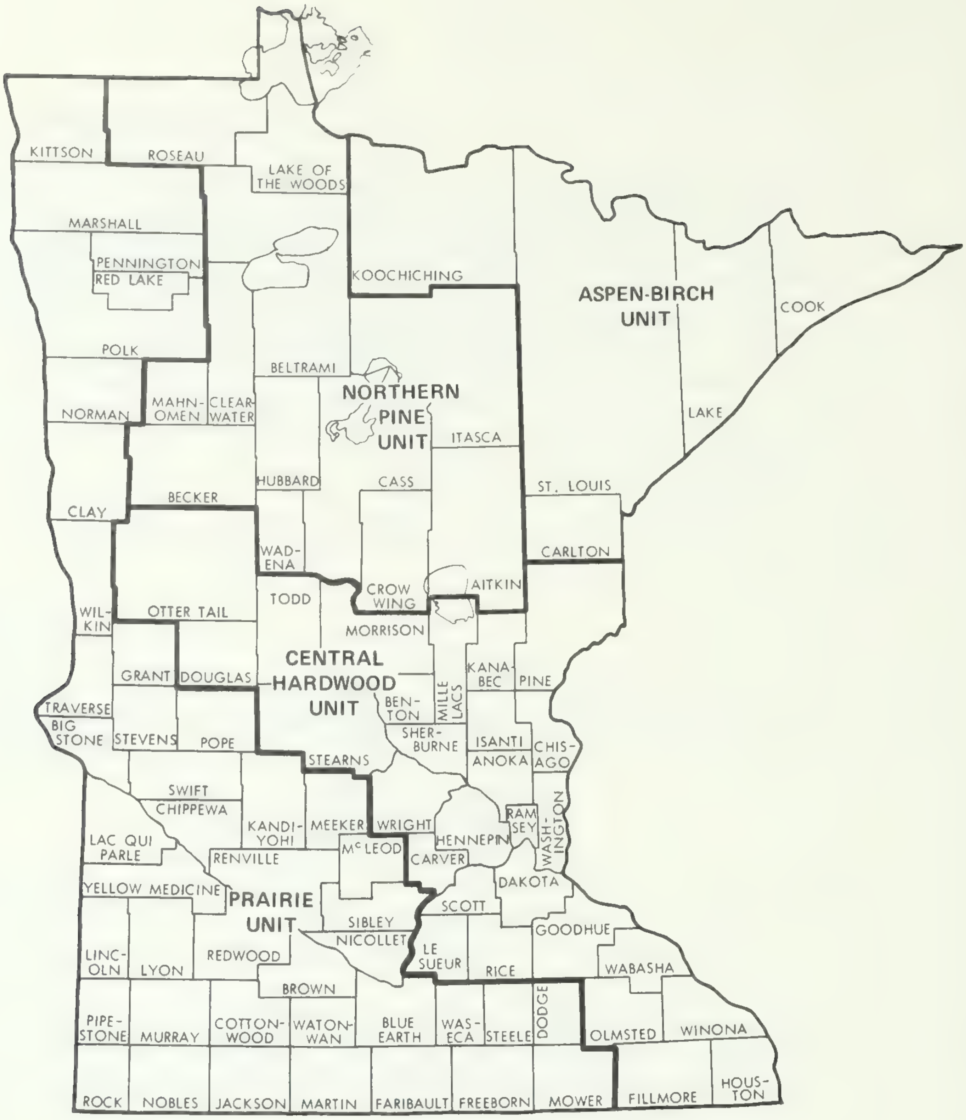

Figure 1. Location of forest inventory units, Minnesota, 1977

Once at the plot, the crew checks to make sure the photograph location agrees with the ground location. All our forest plots are considered permanent and great care is taken to locate, witness, and establish the plot so it can be remeasured later.

Our plots are sampled using a 10-point cluster design. This grid pattern of sample points is designed to obtain a uniform distribution of points over an area of approximately one-acre (fig. 2). Distance from point to point is 70 feet. Point one always determines land class. If point one is forest land and any of the remaining points fall on nonforest land, a substitute point is located on commercial forest land.

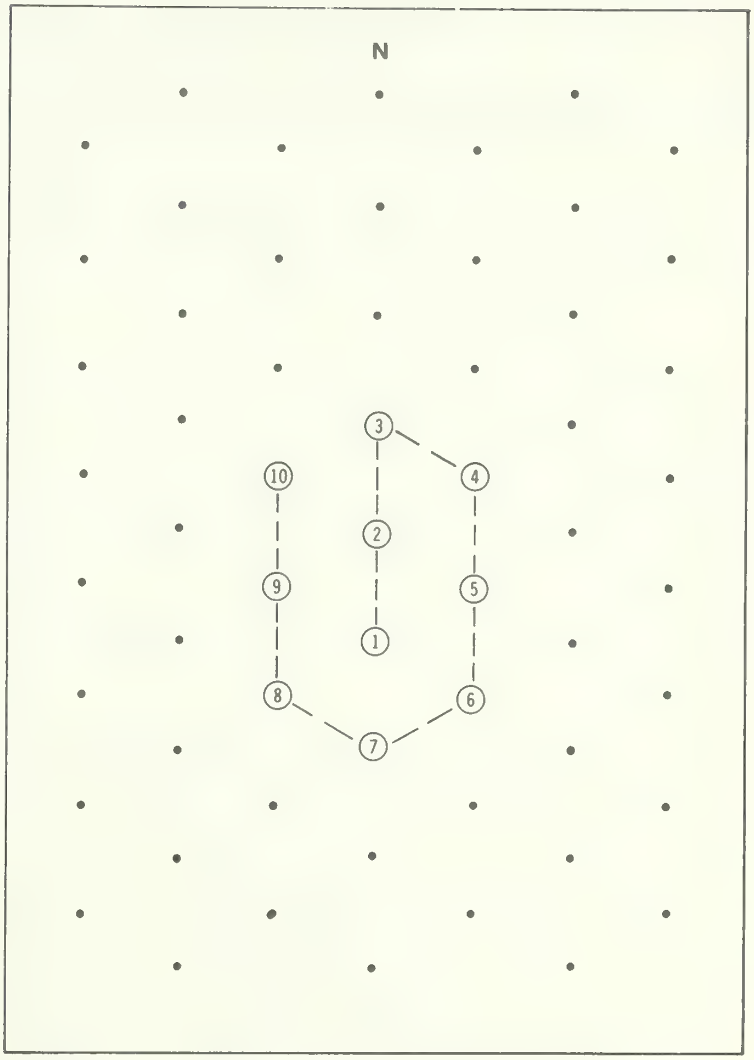

Figure 2. Ten-Point cluster design layout.
Distance from point to point is 70 feet.

At each plot point a 37.5 basal area factor, variable radius plot is established for all live trees 5.0 inches d.b.h. and larger that fall within the limiting distance. Trees are determined to be in or out of the tally depending on their d.b.h. and distance from the point center. For example, the limiting distance for a tree with a d.b.h. of 14.6 inches is 20.7 feet. A glass prism is used to determine which trees should be tallied, although the distance from point center to borderline trees is measured by tape.

Sapling-size trees (1.0 to 5.0 inches d.b.h.) are tallied on a fixed plot at each point (6.8 foot radius). Information on species, diameter, and tree class are recorded on these trees. Seedlings can also be recorded if the required number of saplings are not on the plot.

A tally of stumps cut within the last 3 years on a fixed radius plot (16.6 feet) is also made at each point. From this data, estimates can be computed of timber volume removed.

Up to 24 separate items can be recorded on our field plot sheets for each individual tree. Items recorded for a tree fall into one of three main groups: tree identification, tree measurement, and tree classification.

Each of the tally trees is identified by azimuth and distance from point center. Point number, tree number, tree history (live, dead, stump), and species were also recorded.

A permanent mark is placed on each tally tree at d.b.h. and at the base. Individual tree species is also recorded; in Minnesota 43 separate commercial tree species were recorded.

Tree measurements and observations are used to compute volume, growth, and quality. They include tree diameter, merchantable tree heights, and log grade.

Precise measurements and classifications are essential to keep field technique errors to a minimum because these errors will be expanded several hundred times during the data processing.

Tree diameter at breast height is a critical measurement and must be properly and accurately determined. It is used to determine if trees are in or out of the tally, and it is remeasured on subsequent surveys to determine growth. Diameter breast high is defined as tree diameter outside the bark at 4.5 feet above the ground.

Merchantable bole length of all growing-stock trees 5.0 inches d.b.h. and larger is determined as the distance between the top of a 1-footstump and a 4.0 inch top diameter outside bark, or the point at which the central stem is terminated by branches or rot. Cull is recorded for sections of trees that have forks, excessive limbs, sweep, crook or rot.

Saw log length is recorded for trees 9 inches d.b.h. and larger for softwoods and 11 inches d.b.h. and larger for hardwoods. It is measured from a 1-foot stump to the point on the bole above which no merchantable saw log can be produced because of excessive limbs or other defects, or to a minimum top diameter outside bark of 7 inches for softwoods and 9 inches outside bark for hardwood. To qualify as a sawtimber tree it must contain at least one 12 foot log or two 8 foot or longer logs; meet minimum saw log grade specifications; and contain 33 percent or more of the gross board foot volume in sound material.

The first saw log in each live sawtimber tree is log-graded. Log grade is a classification of logs based on external characteristics as indicators of quality and value.

The items listed below are recorded for all live trees of commercial species that are 5 inches d.b.h. or larger. These characteristics provide the basis for systematically grouping trees into classes that reflect their vigor and suitability for timber products.

Surface defects provide a measure of the number and size of limbs, knots, and external flaws that affect lumber and veneer quality.
Internal defects, sweep and crook are items that give estimates of tree's volume lost because of these defects.
Relative bole length, crown ratio, and crown class supply estimates of crown vigor and crown position.
Damage or pathogen activity furnish estimates of tree volume lost to these causes.

From the tree classification items listed above, tree classes of live trees are determined. Desirable and acceptable tree classes have traditionally been grouped together and called growing-stock or merchantable trees. Rough and rotten tree classes are grouped together and called cull or nonmerchantable trees.

The following Information is recorded at each ground location to describe the stand in which the plot falls:

Ownership class
Stand origin
Site class
Site index
Physiographic class
Stand age
Seed source
Forest type
Stand-size class
Aspect-position-slope
Basal area per acre
Stand history
Stand area
Distance to water and road
Conifer understory

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LAKE STATES' RESOURCE TRENDS

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Demand for forest resources is often exerted across broad regions, with little regard for political boundaries. For example, loggers, campers, hunters, and other forest users in Minnesota, Wisconsin, and Michigan frequently look beyond the boundaries of their home State to the Lake States Region to satisfy their demand for timber and nontimber forest resources. The purpose of this paper is to examine the forest resources of the three Lake States and to compare them to the forest resources of other areas of the Country. By presenting the statistics and comparisons in one package a complete picture can be obtained of the Lake States' forest resources and the Region's place in the United States forest picture.

State-wide forest inventories provide the basic data needed to assess a State's forest resources. However, it is often difficult to compare statistics from different States or combine data from several States due to different inventory dates. The assessment document produced in compliance with the Forest and Rangeland Renewable Resources Planning Act of 1974 (P.L. 93-378) is the one source of statistics for all States in a common year. In the assessment just being completed, the most recent forest inventory data for each state was updated to 1977. Preliminary statistics from the update are the basis for this paper.1/

Area

In 1977, forest land in the United States covered 738.5 million acres which is one-third of the Nation's total land area. This amounts to 3.5 acres of forest land per person in the United States. Forests are not distributed evenly across the Country, but rather are concentrated in the South, Pacific Coast, and Rocky Mountain Regions (fig. 1). The Lake States Region contains 9 percent of the Nation's land area and only 7 percent of the forest land area.

1/ USDA Forest Service. 1978. Forest Statistics of the United States, 1977. Review draft. 133 p. Minnesota statistics published in the review draft were updated from the 1962 forest inventory. The final document will contain the new 1977 Minnesota forest inventory data. Lake States statistics used in this paper were adjusted for the new Minnesota forest inventory data.

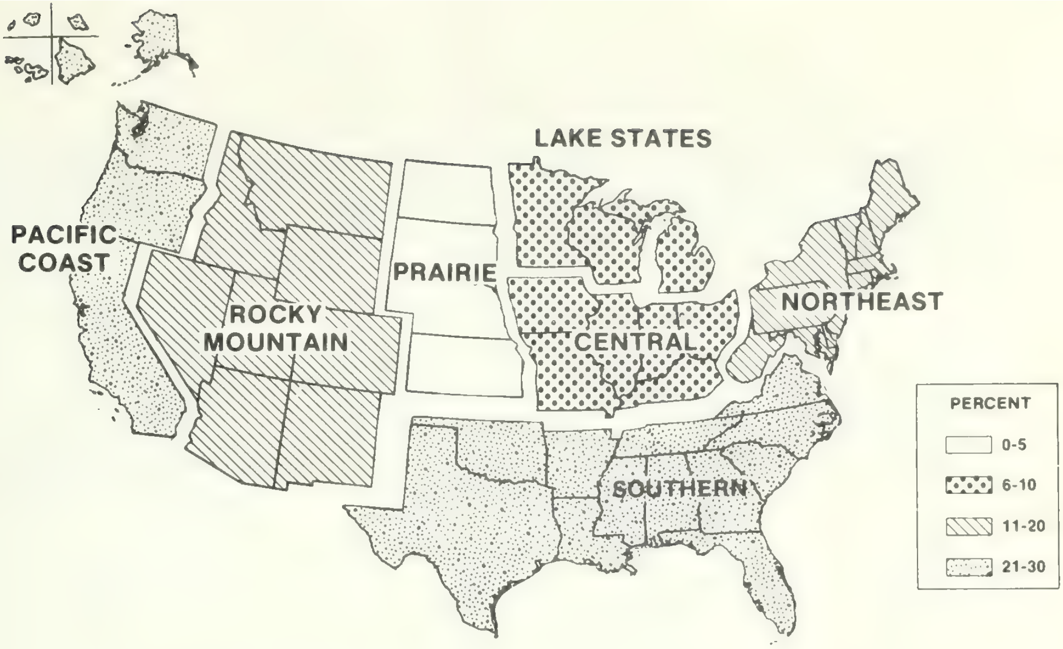

Figure 1. Distribution of the Nation's forest land among regions, 1977

Forest land is divided into three land-use categories: commercial, unproductive, and productive-reserved. Unproductive and productive-reserved forest land are often grouped together and called noncommercial forest land. During forest inventories efforts are concentrated on gathering data on commercial forest land because it is the portion of the forest area capable of producing crops of wood and available for timber utilization. In most regions, commerial forest land accounts for a majority of the forest area:

Region	Forest land	Commercial forest land	Noncommercial forest land
		(Million acres)	
Pacific Coast	214.5	70.8	142.7
Rocky Mountain	136.4	56.5	79.9
South	207.1	188.4	18.7
Northeast	84.3	79.2	5.1
Central	40.8	39.6	1.2
Prairie	4.5	3.8	0.7
Lake States	50.9	47.0	3.9
All Regions	738.5	485.3	253.2

Exceptions to this are the Pacific Coast and Rocky Mountain Regions in which the majority of the forest area is unproductive forest land. Unproductive forest land is incapable of producing wood crops and in the West, includes chapparel areas. The third forest category is productive-reserved forest land--land that is productive enough to be commercial forest but has been withdrawn from timber utilization through statute or administrative regulation. In the Lake States, 92 percent of the forest area is commercial forest, 5 percent is unproductive, and 3 percent is productive-reserved.

Nationwide, commercial forest area has declined since 1952. The decline was observed in all regions except the Northeast, in which tree stocking on some nonforest land and wooded pasture increased and was reclassified as commercial forest:

Region	Change (Percent)
Pacific Coast	-5
Rocky Mountain	-10
South	-2
Northeast	+9
Central	-5
Prairie	-11
Lake States	-8
All Regions	-3

Commercial forest area in the Lake States has declined an average of 0.3 percent per year since 1952 (fig. 2). Since 1970, the rate of decline has slowed over that reported between 1952 and 1970.

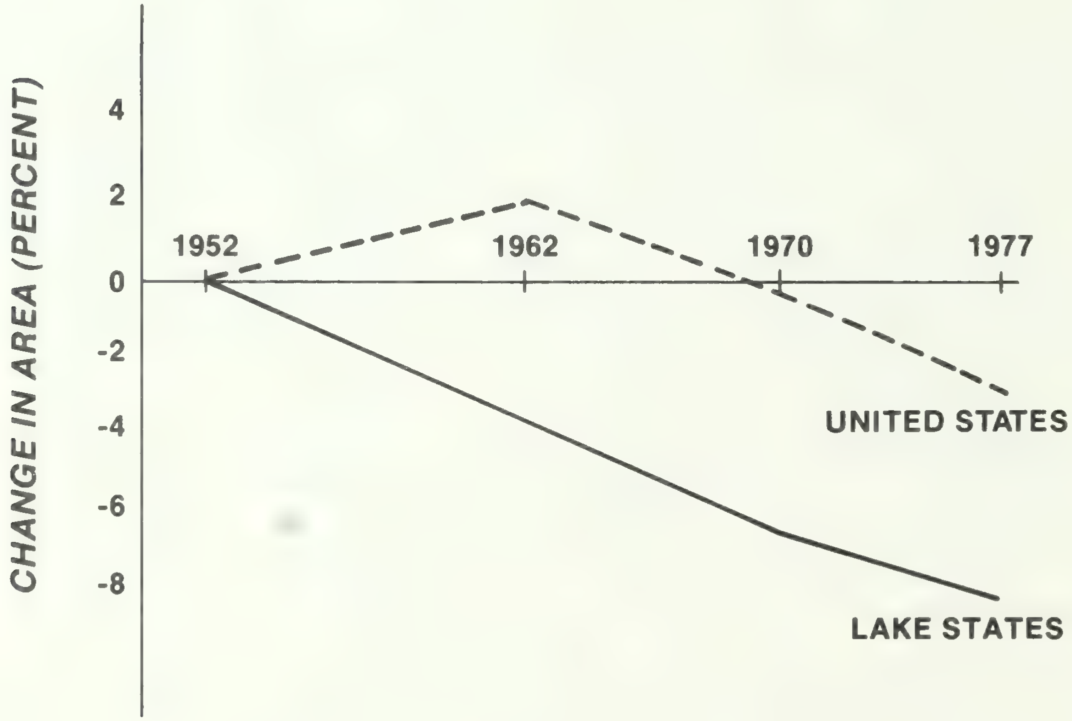

Figure 2. Change in commercial forest area, Lake States and total United States.

The majority of the commercial forest land in the Country is owned by private individuals and corporations. Farmers hold 24 percent of the commercial forest area and miscellaneous private owners another 34 percent:

Ownership Class	Commercial Forest Land	
	United States	Lake States
	(Million acres)	
National Forests	88.7	5.3
Other federal agencies	16.8	1.2
States	23.1	7.1
County and municipal agencies	6.9	4.8
Forest industries	67.9	4.2
Farmers	117.0	11.6
Miscellaneous private owners	164.9	12.8
All owners	485.3	47.0

The dominance of publicly owned commercial forest land in a region varies widely (fig. 3). In the Rocky Mountain Region, 75 percent of the commercial forest area is publicly owned, while in the South and Central Regions, only 9 percent is publicly owned. Thirty-nine percent of the Lake States' commercial forest land is publicly owned. An unusual situation exists in the Lake States--large areas of commercial forests are owned by State, county, and municipal agencies (25 percent of the commercial forest area). More than 30 percent of the State-owned commercial forest land and 70 percent of the county and municipal commercial forest land in the United States is found in the Lake States.

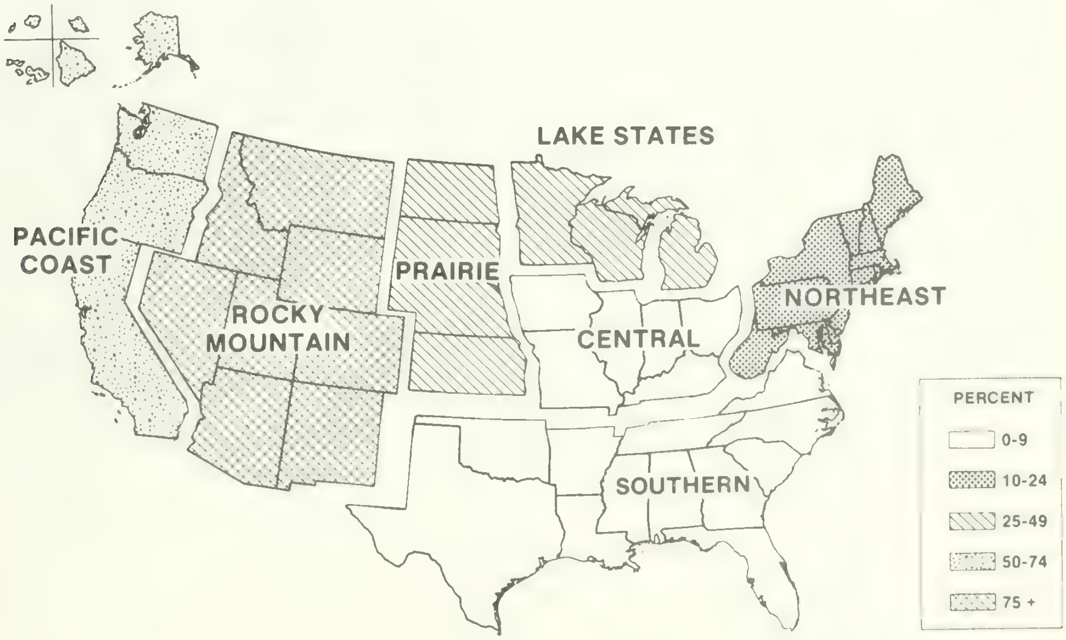

Figure 3. Publicly owned commercial forest land by region, 1977

Climatic, edaphic, and topographic factors affect the distribution of forest types across the Country. In the eastern regions (where nearly three-quarters of the commercial forest land is located) oak-hickory is the most common forest type, while in the West, Douglas fir is most common (fig. 4). The Lake States Region holds a large portion of the area of several commercially important forest types:

Forest Type	Area in eastern regions[2/] (Million acres)	Area in Lake States (Percent)
White-red-jack pine	12.0	32
Spruce-fir	17.5	42
Longleaf-slash pine	17.0	--
Loblolly-shortleaf pine	49.9	--
Oak-pine	34.5	--
Oak-hickory	110.7	5
Oak-gum-cypress	26.9	--
Elm-ash-cottonwood	24.2	15
Maple-beech-birch	33.3	30
Aspen-birch	20.5	76
Nonstocked	10.2	11
All types	356.7	13

The distribution of timber stands among stand-size classes reflects stand history and timber management practices in a region. Forty-four percent of the Nation's commercial forests is in sawtimber stands, with the remaining acreage fairly evenly divided between poletimber and seedling and sapling stands. In areas in which old-growth stands predominate, such as the Pacific Coast and Rocky Mountain Regions, more than 65 percent of the commercial forest land is in sawtimber stands (table 1). In the South, a large portion of forest area is intensively managed so forests are fairly evenly divided among the three stand-size classes. The Lake States Region is the only region that does not have the largest portion of its commercial forest area in sawtimber stands. Forty-six percent of the Lake States area is in poletimber stands, with seedling and sapling stands accounting for 23 percent and sawtimber stands 24 percent. Nonstocked commercial forest areas cover the remaining 2 percent.

[2/] Eastern regions include Lake States, Northeast, South, Central and Prairie Regions.

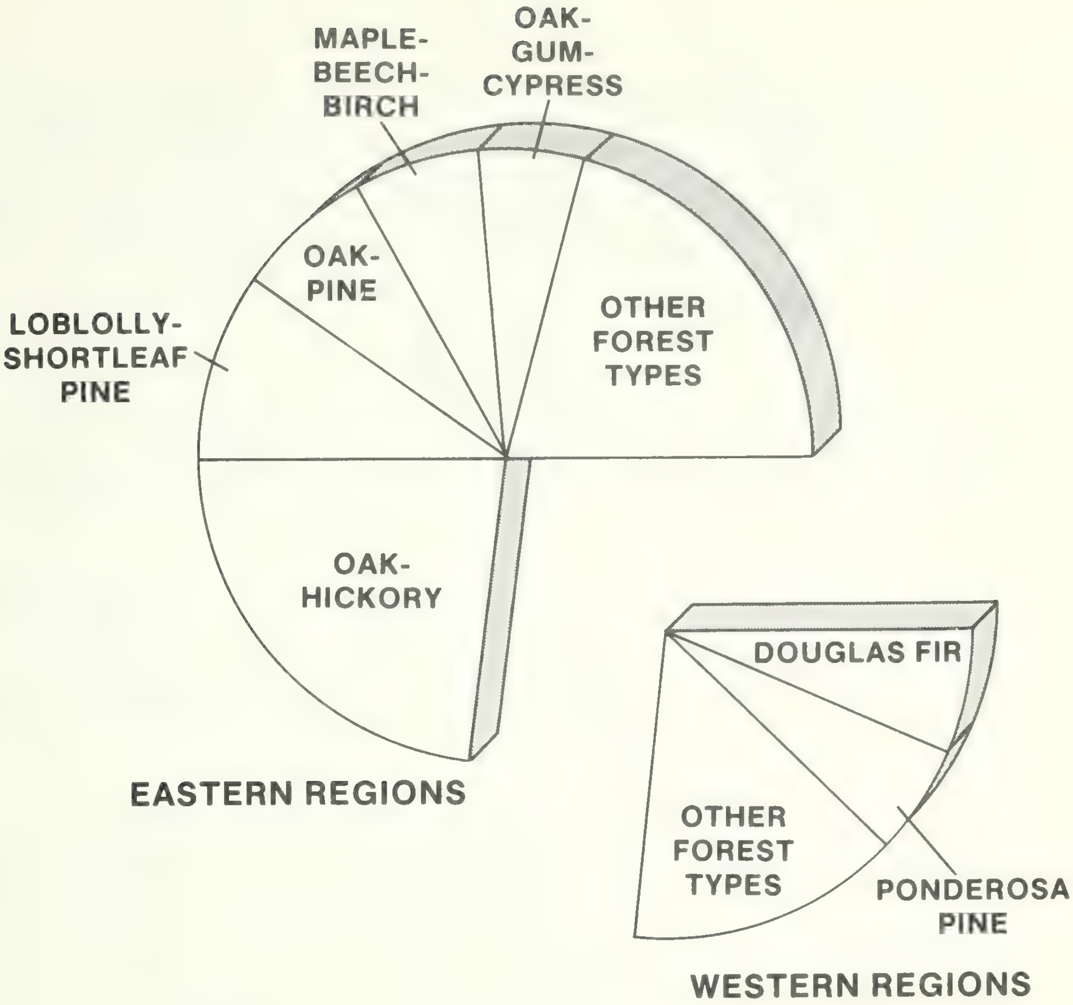

Figure 4. Distribution of commercial forest land by forest types, eastern regions and western regions, United States, 1977

Table 1.--Area of commercial forest land by region and stand-size class, United States, 1977

(In million acres)

Region	Total	Stand-size class			
		Sawtimber	Poletimber	Seedling & Sapling	Nonstocked
Pacific Coast	70.8	46.3	10.0	10.6	3.9
Rocky Mountain	56.5	37.7	11.4	4.9	2.5
South	188.4	68.4	57.3	57.6	5.1
Northeast	79.2	30.9	23.4	22.8	2.1
Central	39.6	16.4	10.8	11.1	1.3
Prairie	3.8	1.9	1.0	0.4	0.5
Lake States	47.0	11.0	21.8	13.1	1.1
Total	485.3	212.6	135.7	120.5	16.5

When compared to the rest of the Nation, the productive potential of the Lake States' forests is low. Site-class ratings assess an area's productive potential in terms of cubic feet of growth per acre per year in fully stocked natural stands at culmination of mean annual increment. The average productive potential outside the Lake States is 73 cubic feet, while the Lake States's productive potential is only 55 cubic feet.

Volume

While commercial forest area has declined, growing-stock volume has increased since 1952. Nationwide, growing-stock volume has increased 19 percent during the 25 year period. The increase in growing-stock volume of hardwoods has been more dramatic than that of softwoods.

Softwood volume rose 33.4 billion cubic feet (8 percent) between 1952 and 1977 (fig. 5). This increase was observed in all regions except the Pacific Coast Region in which softwood volume fell 12 percent. The largest percent increase in softwood volume occurred in the Lake States Region. The continuing maturation of the Region's forests resulted in a 76 percent increase in softwood growing-stock volume during the time period (fig. 6).

In the eastern regions (Northeast, South, Central, Prairie, and Lake States Regions), loblolly and shortleaf pines account for half of the 141.8 billion cubic feet in softwood species. The Lake States account for a large percentage of the volumes of several species groups, notably jack pine, eastern white pine-red pine and spruce-fir:

	Softwood growing-stock volume	
Species group	Eastern regions	Lake States
	(Billion cubic feet)	
Jack pine	1.6	1.6
White-red pine	10.8	2.4
Spruce-fir	19.5	4.1
Eastern hemlock	6.7	1.2
Other softwoods	103.2	2.6
All species	141.8	11.9

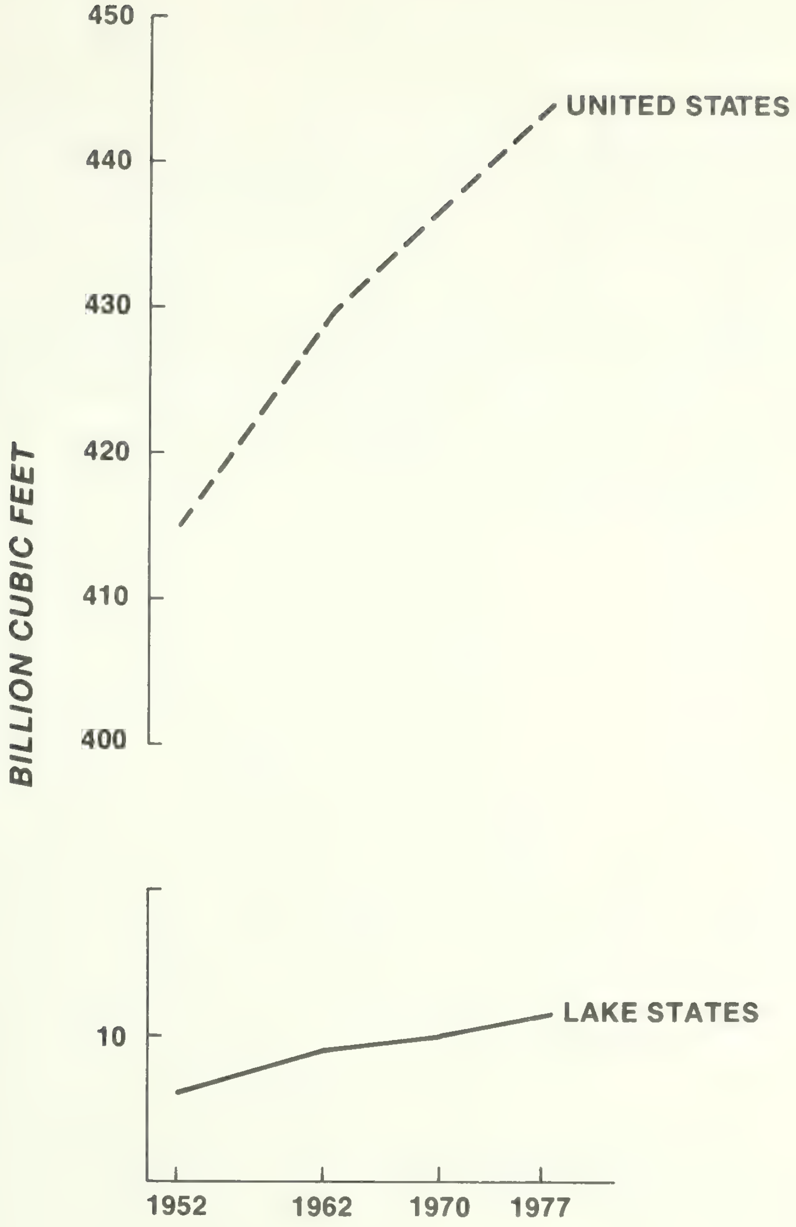

Figure 5. Trends in softwood growing-stock volume, Lake States and United States, 1952-1977

Nationwide, the National Forests account for the largest portion of the softwood growing-stock volume, 46 percent. The National Forests are not nearly so important in supplying softwood volume in the Lake States. The large concentration of Lake States' volume in other public owners reflects the importance of State, county and municipal agencies in forestry in the region:

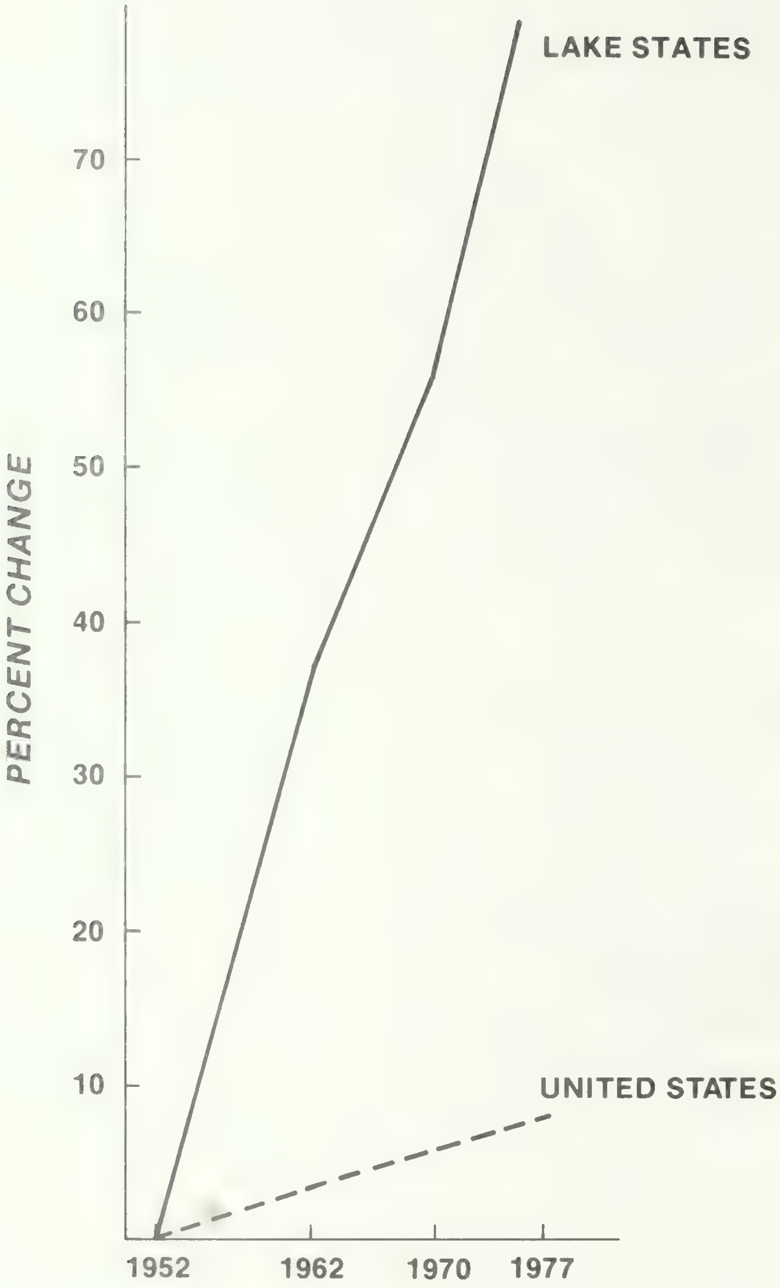

Figure 6.--Percent change in softwoods growing-stock volume, Lake States and United States

Ownership class	Softwood growing-stock volume United States	 Lake States
	(Percent)	
National Forest	46	18
Other public	11	30
Forest industry	16	15
Other private	27	37
All owners	100	100

An increase of 79.3 billion cubic feet (45 percent) in hardwood growing-stock volume occurred between 1952 and 1977 (fig. 7). All regions showed an increase but the 72 percent increase in the Lake States' hardwood volume was the largest of any region (fig. 8).

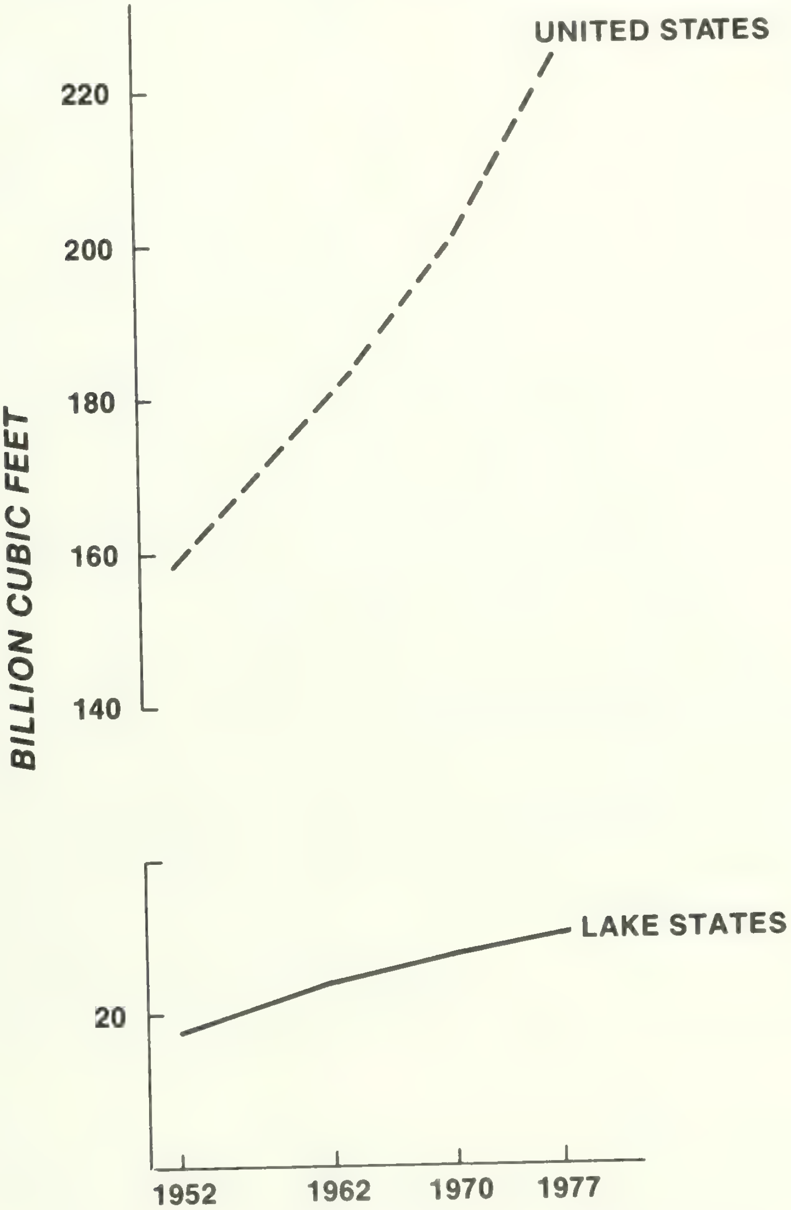

Figure 7.--Trends in hardwood growing-stock volume, Lake States and United States

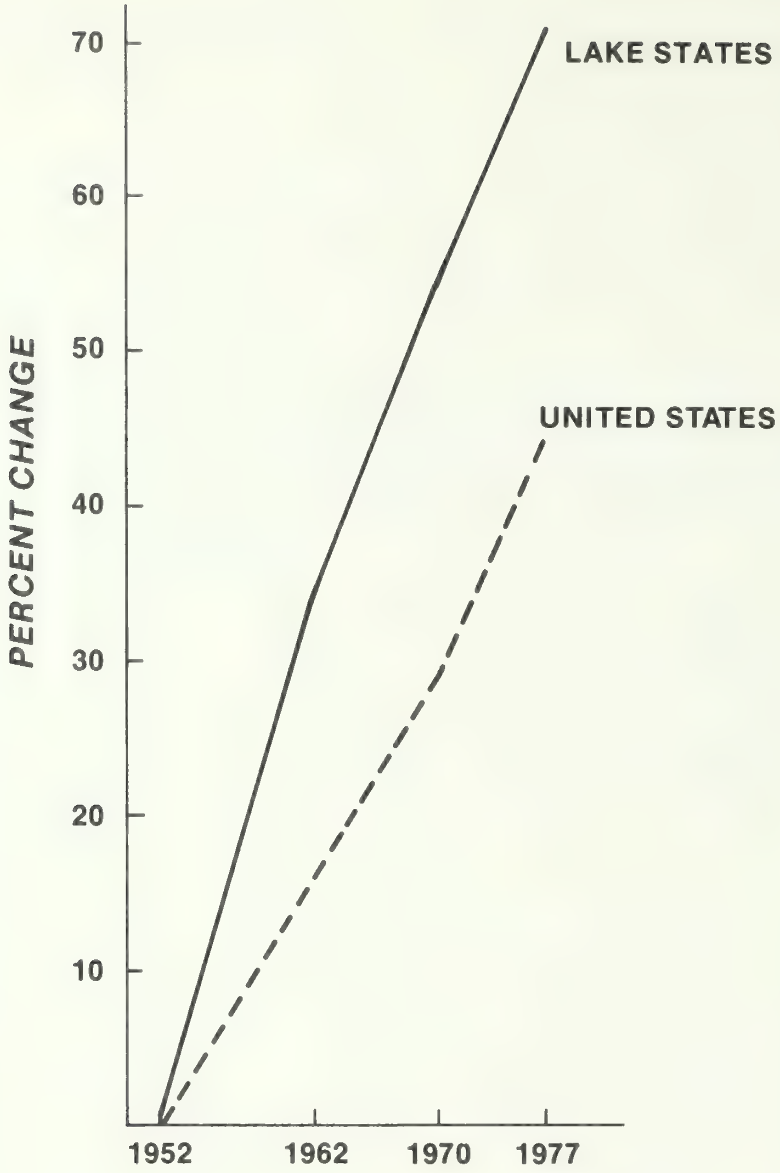

Figure 8. Percent change in hardwood growing-stock volume, Lake States and United States

The oak species account for 30 percent of the 135.4 billion cubic feet of hardwood growing-stock volume, the largest percentage of any species group. The Lake States provide 74 percent of the aspen-cottonwood volume in the East, as well as 31 percent of the ash and 23 percent of the maple volumes:

Species group	Hardwood growing-stock volume	
	Eastern regions	Lake States
	(Billion cubic feet)	
Oaks	5.8	4.8
Maples	12.1	9.0
Aspen-Cottonwood	27.5	6.4
Ash	41.2	4.9
Other hardwoods	48.8	9.3
All species	135.4	31.4

Although National Forests hold the majority of the Nation's softwood growingstock volume, they hold very little of the hardwood growing-stock volume. Again, the importance of other public owners in the Lake States is shown.

Ownership class	Softwood growing-stock volume United States	 Lake States
	(Percent)	
National Forest	8	10
Other public	10	24
Forest industry	12	10
Other private	70	56
All owners	100	100

Growing-stock volume increases despite declines in commercial forest area when growing-stock volumes per acre of commercial forest land also increase. In 1952 there were an average of 1,199 cubic feet of growing-stock per commercial forest acre, but in 1977 the volume per acre had increased 22 percent to 1,466 cubic feet. The differences in volumes per acre among regions reflect the distribution of commercial forest area among stand-size classes. In the Pacific Coast Region, where so much land contains sawtimber stands, growing-stock volume per acre is much higher than that of any other region. In the Lake States there are more seedling and sapling stands than sawtimber stands, growing-stock volume per acre is much lower than the national average:

Region	Growing-stock volume per acre of commercial forest land (cubic feet)
Pacific Coast	3,341
Rocky Mountain	1,737
South	1,067
Northeast	1,261
Central	750
Prairie	795
Lake States	921
All regions	1,466

Volumes per acre also vary widely by ownership class. Nationwide, National Forests have the highest growing-stock volumes per acre; however, in the Lake States, forest industry ranks first:

Ownership class	Growing-stock volume Per acre of commercial forest land United States	Lake States
	(Cubic feet)	
National Forests	2,570	989
Other public	1,621	844
Forest industry	1,546	1,158
Other private	1,075	904
All owners	1,466	921

Growth and removals

The volume of growth and removals has increased in the Lake States and the Nation since 1952. Nationwide, growth of softwood species increased from 7.8 million cubic feet to 12.3 million cubic feet, and the growth rate (growth as a percent of inventory) increased from 2 percent to 3 percent. Increases in removals were not as great as increases in growth. In 1952, softwood removals were equal to growth but by 1977, removals were only 82 percent of growth.

Although the volume of softwood growth and removals in the Lake States also increased between 1952 and 1977, growth rates and removal rates declined. A decline in growth rates is not unusual for states in which the inventory has been increasing rapidly. In these cases, growth volumes cannot keep pace with inventory volumes and growth rates decline:

	1952	1977
Growth (thousand cubic feet)	302.5	465.3
Growth rate	4.6	3.9
Removals (thousand cubic feet)	141.8	181.0
Removals rate	2.1	1.5

In the Lake States, the ratio of removals to growth is not as high as in the Nation as a whole. In 1952, softwood removals in the Lake States were 47 percent of growth and by 1977 had declined to 32 percent of growth (fig. 9).

Hardwood growth Nationwide increased from 6.2 million cubic feet in 1952 to 9.5 million cubic feet in 1977. Growth rates increased slightly from 1.8 to 2.2 percent of inventory. Increases in hardwood removals were small from 4.1 million cubic feet to 4.3 million cubic feet. Removals rates declined from 2.3 percent to 1.6 percent of inventory during this period.

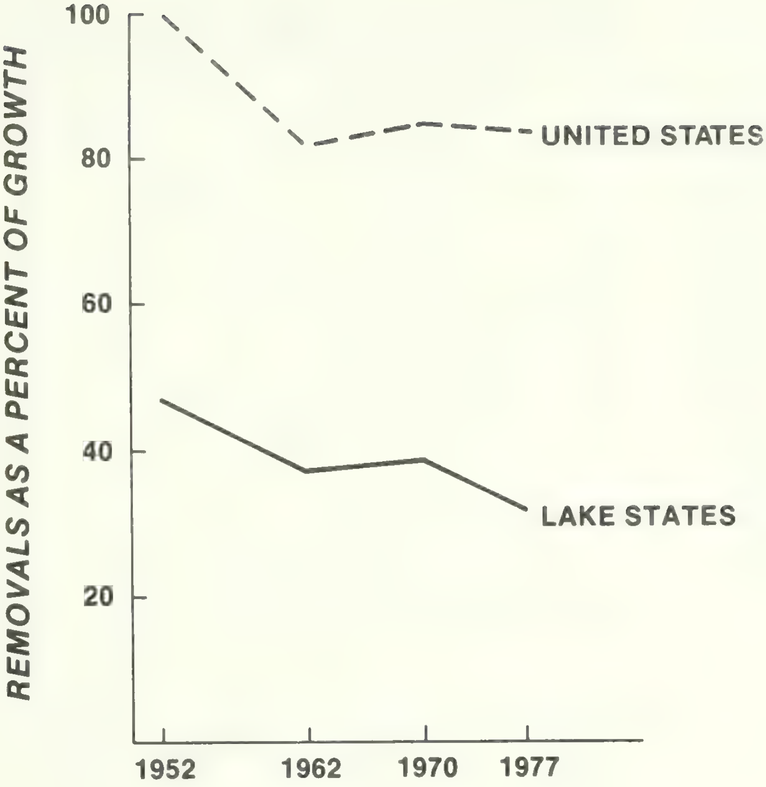

Figure 9.--Softwood growing-stock removals as a percent of softwood growing-stock growth, Lake States and United States

Although har ls volume in the Lake States
incre)wth and removals rates decreased:

1952	1977
854.0	1,120.2
4.7	3.6
370.1	521.0
2.0	1.7

emovals as a percent of growth
states as changes in technology and development
began to more fully utilize the hardwood resource

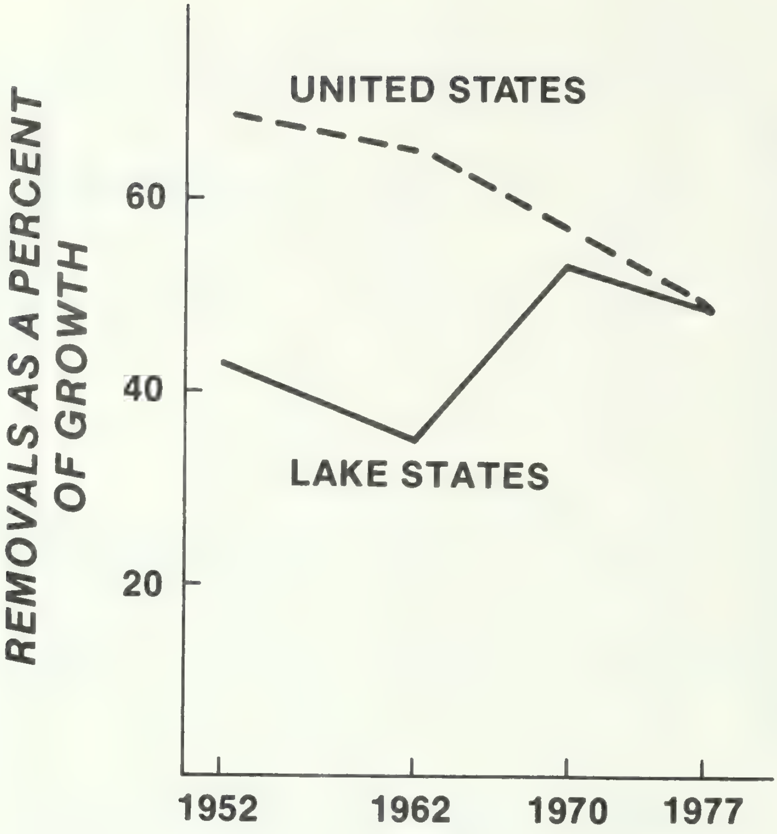

Figure 10. Hardwood growing-stock removals as a percent of hardwood growing-stock growth, Lake States and United States

Most of the growing-stock removals in the Lake States and the Nation went to products:

Removals	United States	Lake States
	(Percent)	
Sawlogs	44	20
Veneer logs and bolts	9	1
Pulpwood	24	38
Miscellaneous industrial products	2	4
Fuelwood	4	8
Logging residue	9	4
Other removals	8	25
All removals	100	100

An unusually large percentage of the Lake States' removals go to other removals. Other removals are trees actually cut or downed during land clearing or cultural operations but not used for products, and trees left standing but "removed" from the commercial forest land base due to changes in land use.

Summary

This has been a brief sketch of the Lake States' timber resource. Highlights from the discussion include:

-- Commercial forest land in the Lake States decreased 8 percent between 1952 and 1977.

-- A large percentage of the Country's State, and county and municipal commercial forest land is found in the Lake States.

-- 76 percent of the aspen-birch acreage, 42 percent of the spruce-fir acreage, 32 percent of the white pine acreage, and 30 percent of the maple-beech-birch acreage found in the eastern regions is found in the Lake States.

-- The largest portion of the Lake States' commercial forest land is in poletimber stands.

-- The productive potential of the Lake States' forests is low.

-- The percent increase in growing-stock volume in the Lake States exceeded all other regions.

-- Growing-stock volume per acre of commercial forest land is 921 cubic feet in the Lake States, compared to 1,466 for all regions.

-- Growth and removals volumes in the Lake States have increased since 1952.

-- In the Lake States, 71 percent of growing-stock removals goes to products, 25 percent to other removals, and 4 percent to logging residue.

MINNESOTA TIMBER UTILIZATION

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Primary Industry

Minnesota's primary wood-using industry is concentrated in the eastern half of the State with the largest mills primarily in northeast and north central counties (fig.1). In 1975, out of 229 active primary mills, 8 were pulpmills, 199 were sawmills, and the remainder were veneer, cooperage, particleboard, and other specialty mills. Eight sawmills each produced 5 million board feet or more of lumber and 29 others each produced from 1 to 5 million board feet.

Total timber products harvested in 1975 were 158 million cubic feet (nearly 2 million cord equivalents). Forty-four percent of the volume was harvested on farm and other small private ownerships and 10 percent was harvested on forest industry land. State-owned land contributed 20 percent, county land 12 percent, National Forests 11 percent, and other Federal land 3 percent.

Minnesota loggers harvested three major products in 1975--pulpwood (63 percent of the total), saw logs (18 percent), and fuelwood (13 percent). The remainder was in a variety of products such as veneer logs, cooperage logs, and posts.

Aspen (42 percent) dominated the timber products harvest followed by jack pine (14 percent), spruce (11 percent), oak (7 percent), and balsam fir (6 percent). Hardwoods constituted about 60 percent of the harvest.

Pulpwood

Pulpwood production was 1.36 million cords in 1975 and was concentrated in aspen, spruce, pine, and balsam fir (table 1). Unlike the other Lake States, mixed hardwood (excluding aspen) was only a small portion of the Minnesota pulpwood harvest and has never exceeded 7 percent.

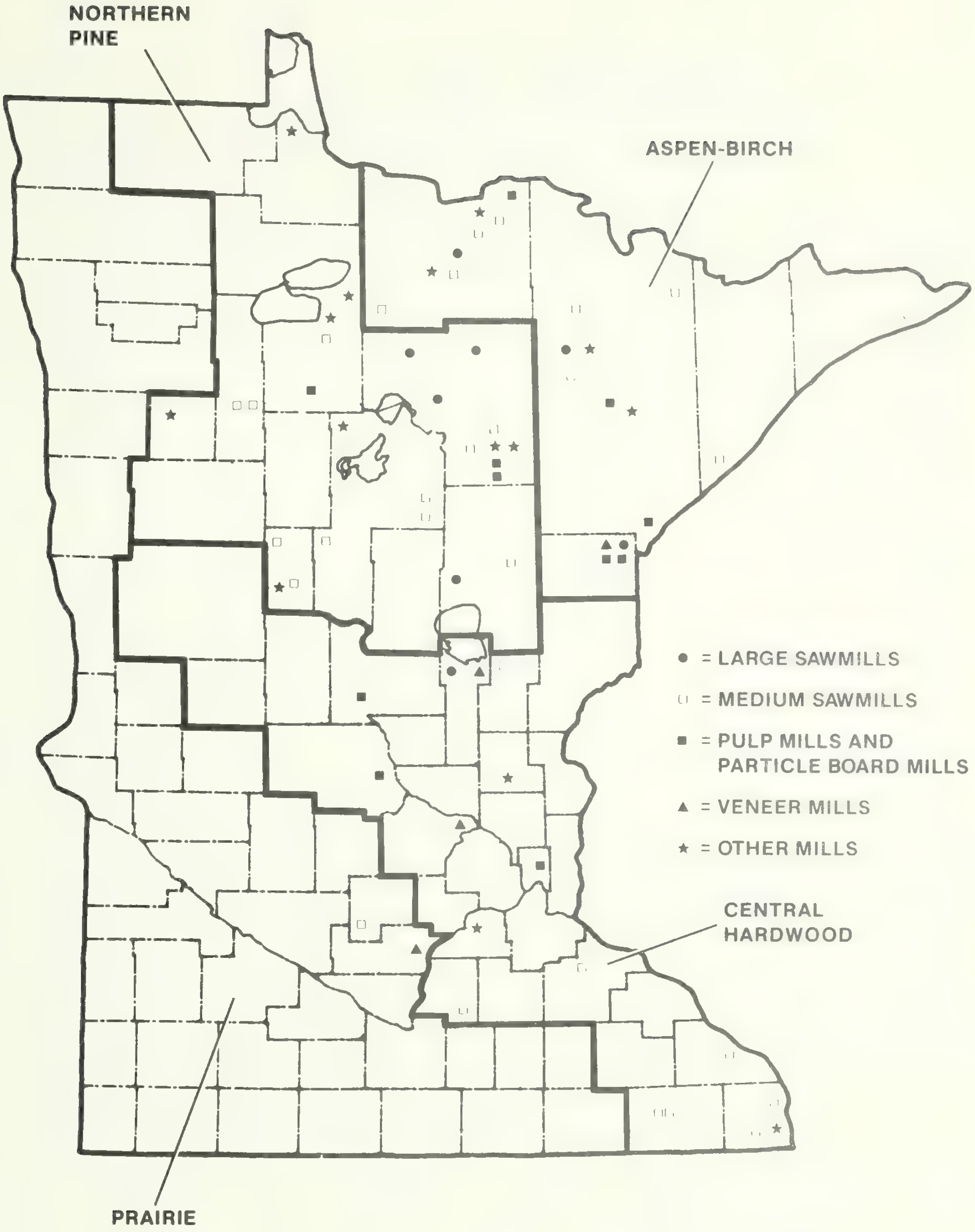

Figure 1. Primary wood-using mills and inventory units in Minnesota, 1975. Large sawmills each produced 5 million board feet or more of lumber, and medium sawmills each produced from 1 to 4.999 million board feet.

Table 1.-- Pulpwood production by species,
Minnesota, 1960 and 1975

(In thousand standard cords, unpeeled)

Species	1960	1975	change
Softwoods:			
From roundwood:	645	578	-67
Spruce	256	202	-54
Pine	225	199	-26
Balsam fir	145	121	-24
Tamarack	19	56	37
From mill residue:	0	44	44
All softwoods	645	622	-23
Hardwoods:			
From roundwood:	403	673	270
Aspen	392	616	224
Paper birch	1	35	34
Other hardwoods	10	22	12
From mill residue:	0	64	64
All hardwoods	403	737	334
All species	1,048	1,359	311

Since 1950, pine and spruce pulpwood production has been in a slight downward trend but with several large annual increases and decreases (fig. 2). Balsam fir output was trendless during the 1950's, but began declining in 1961, bottomed out in 1971, and has climbed erratically since then.

Aspen pulpwood production has climbed from about 250,000 cords in 1950 to 600,000 cords or more during the 1970's (fig. 3). Overall, pulpwood harvest trends have been upward during the last 25 years.

Minnesota primary wood-using mill residue was first used for manufacturing pulp on a regular basis in 1964 and in recent years has been 7 to 8 percent of total pulpwood production.

Pulpwood production varies from year to year with changes in the business cycle and adjustments in pulpwood inventories at pulpmills. Usually annual pulpwood production gains for 1 to 3 years are followed for a year or two by declines of less magnitude.

Whole tree chips are becoming an important part of total pulpwood production. Pulpwood production from whole tree chips advanced from 69,000 cords in 1975 to 141,000 cords in 1978.

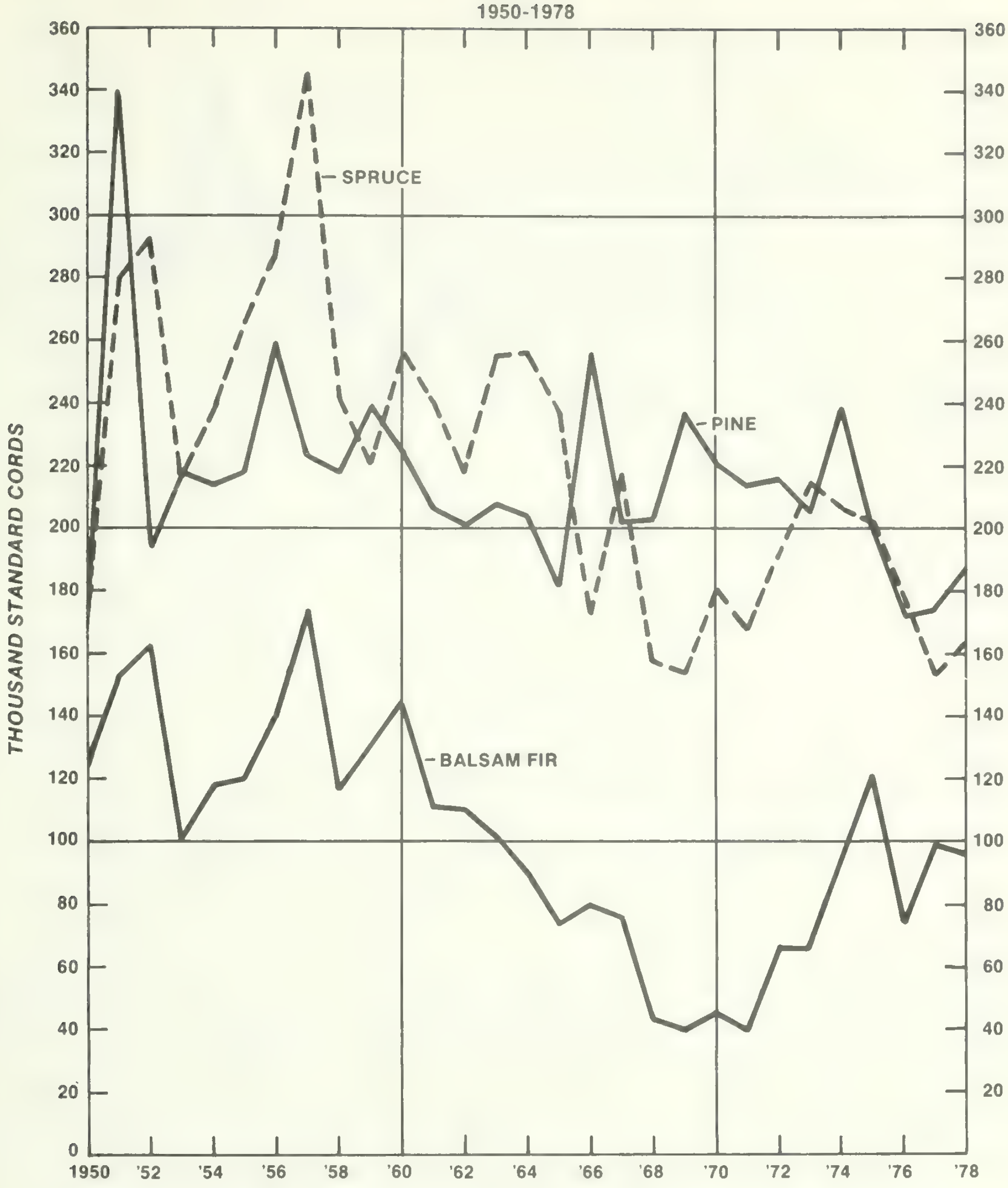

Figure 2. Minnesota round pulpwood production from selected softwood species groups, 1950-1978.

Other Products

Minnesota loggers cut 156 million board feet of saw logs in 1975, down 12 million board feet from 1960, (table 2). However, because 1975 was a recession year and 1960 was a more average year in the economy, no special significance should be attached to the lower production in 1975. In an average year, saw log production is probably higher than in 1960. Despite the low level of production in 1975, aspen and jack pine were in greater demand than in 1960. Both species are heavily used in construction and aspen is in demand for pallets and furniture stock.

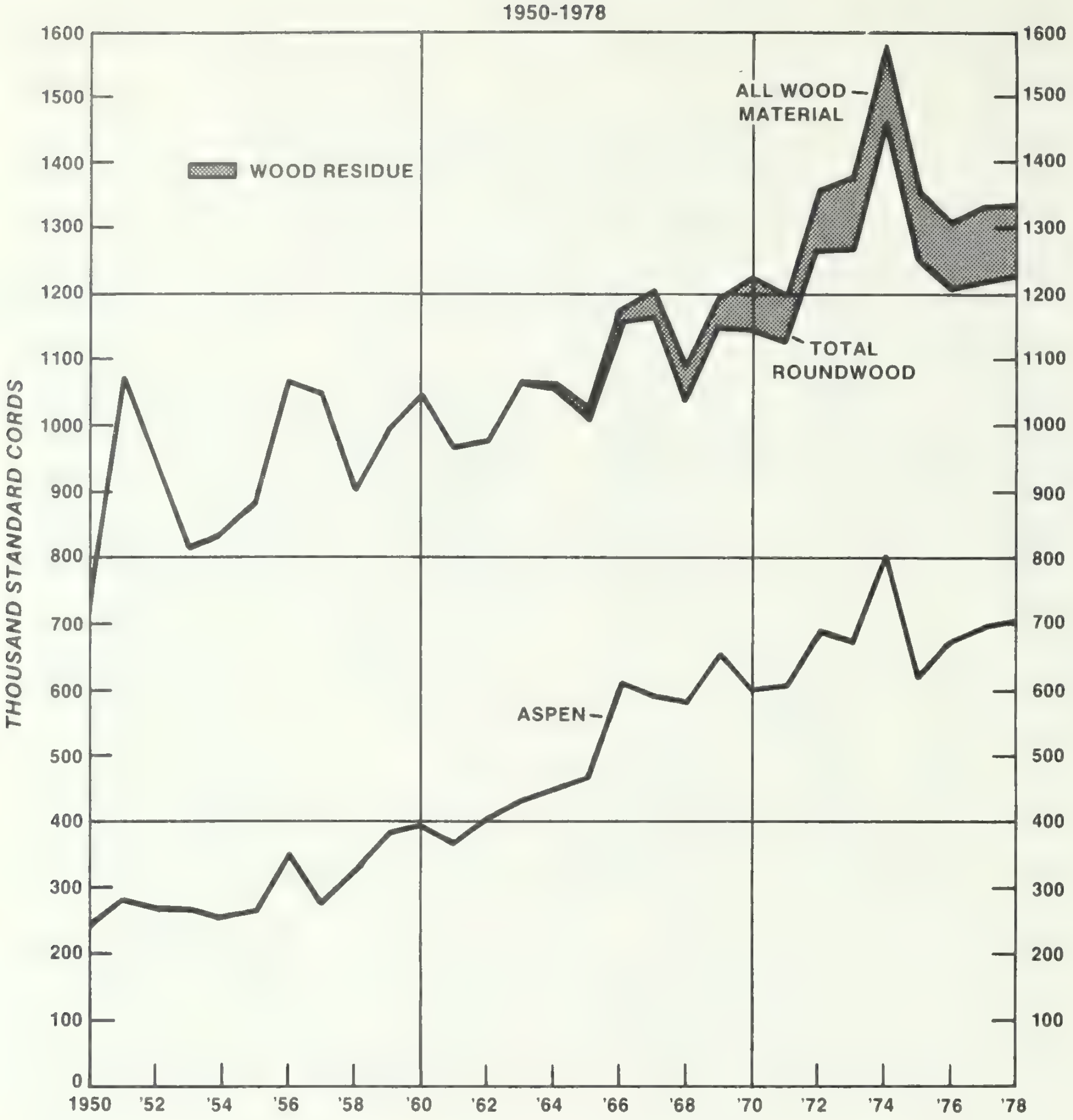

Figure 3.--Minnesota pulpwood production from aspen, all roundwood, and all wood material, 1950-1978

Minnesota exported nearly 4 million board feet of saw logs and imported about one-half million board feet. Wisconsin was the major customer for Minnesota logs and Iowa supplied the imported logs.

Minnesota produced 3.2 million board feet[1/] of veneer logs in 1975 and exported 7 out of every 8 thousand board feet. Wisconsin mills were the primary customers because they face heavy competition for veneer logs in their State. Small quantities of veneer logs are shipped to Canada and other countries. Veneer mills in Minnesota received 600,000 board feet of logs in 1975; one-third were imports from Iowa and Wisconsin.

[1/] Veneer log data for Diamond International's mill were excluded from this disucssion to keep operations at that mill confidential.

Table 2.--Saw log production by species,
Minnesota, 1960 and 1975

(In million board feet, Int'l 1/4-inch rule)

Species	1960	1975	Change
Softwoods:			
Jack pine	23.4	29.0	5.6
White pine	25.7	11.3	-14.4
Red pine	16.1	10.7	-5.4
Cedar	2.0	4.6	2.6
Other softwoods	8.9	5.3	-3.6
All softwoods	76.1	60.9	-15.2
Hardwoods:			
Aspen	37.6	49.5	11.9
Oak	19.2	18.5	-0.7
Elm	8.9	9.5	0.6
Basswood	9.2	4.4	-4.8
Other hardwoods	17.1	13.3	-3.8
All hardwoods	92.0	95.2	3.2
All species	168.1	156.1	-12.0

Fuelwood production in rural areas was 343,000 cords in 1975 compared to 607,000 cords in 1960 (table 3). Primary wood-using mills supplied 41,000 cords of wood residue for fuelwood, only half the total supplied in 1960. Oak, paper birch, and aspen are the dominant species burned. An additional 200,000 cords or more of fuelwood were probably cut during 1975 in Minneapolis-St. Paul, Duluth, and other urban areas. The Minnesota Department of Natural Resources showed fuelwood production near 900,000 cords for 1978, including the urban areas.

Residue

Disposal of coarse (chippable) wood residue at primary wood-using mills is no longer a problem. In fact, only 14 percent was not used. Most of the 203,000 green tons of coarse residue generated in Minnesota in 1975 came from sawmills and veneer mills. More than half (52 percent) was used in pulp manufacturing and more than one-quarter (28 percent) as fuel.

However, more markets are needed for fine wood residue and bark residue produced at primary mills. Three-fifths of the 120,000 green tons of fine wood residue was not used. Most of the fines was sawdust and shavings. Fuel markets absorbed only 19 percent and markets for mulch, animal bedding, poultry litter, and similar products took another 14 percent.

Table 3.--Fuelwood production by species in rural Minnesota, 1960 and 1975

(In thousand standard cords)

Species	1960	1975	change
Softwoods:			
From roundwood:	45	17	-28
Jack pine	28	12	-16
Tamarack	17	2	-15
Other softwoods	--	3	3
From mill residue:	23	24	1
All softwoods	68	41	-27
Hardwoods:			
From roundwood:	480	285	-195
Oak	127	85	-42
Paper birch	45	62	17
Aspen	190	56	-134
Elm	31	28	-3
Ash	26	28	2
Other hardwoods	61	26	-35
From mill residue:	59	17	-42
All hardwoods	539	302	-237
All species	607	343	-264

Three-fifths of the 102,000 green tons of bark generated at primary mills was not used, either. Fuel was the major use, accounting for almost one-third (31 percent) of the bark.

An estimated 321,000 cords of logging residue were left after timber harvesting in 1975. Softwood residue (114,000 cords) was concentrated in the Aspen-Birch and Northern Pine Units and only 13 percent of the total was from growing stock (table 4).

Hardwood logging residue (207,000 cords) was significant in the Central Hardwood Unit as well as the northern units and a larger segment (24 percent) was growing stock than in softwoods (table 5).

Timber Removals

Timber removals from growing stock on commercial forest land has three major components--timber products, logging residue, and other removals (table 6). Other removals are growing-stock trees removed but not utilized for products or trees left standing but "removed" from the commercial forest land classification by land use change. Timber removals from growing stock was an estimated 194 million cubic feet in 1976 and timber products was the main component (70 percent). Another 28 percent was other removals, chiefly hardwoods. Lack of markets, lack of interest in marketing timber, inefficient marketing systems, and ignorance of marketing opportunities are primary reasons for the large segment of other removals.

Table 4.--Softwood logging residue by inventory unit, Minnesota, 1975

(In thousand standard cords)

Inventory Unit	Growing stock	Nongrowing stock	Total
Aspen-Birch	9	59	68
Northern Pine	6	39	45
Central Hardwoods	1/	1	1
Prairie	1/	1/	1/
All units	15	99	114

1/ Less than 500 cords

Table 5.--Hardwood logging residue by inventory unit, Minnesota, 1975

(In thousand standard cords)

Inventory Unit	Growing stock	Nongrowing stock	Total
Aspen-Birch	17	70	87
Northern Pine	19	65	84
Central Hardwoods	11	19	30
Prairie	2	4	6
All units	49	158	207

A comparison by county for 1976 of growing-stock removals from all species in cords per 1,000 acres of commercial forest land shows where timber may be over or underutilized from a sustained yield basis (fig. 4). The heaviest removals were in the Twin Cities area and in southwestern Minnesota. More than 500 cords per 1,000 acres of commercial forest land were removed from 16 counties in 1976: overcutting was likely in some of these counties. Growing-stock removals were light in northern, north central, and southeastern Minnesota for all species lumped together.

Table 6.--Timber removals from growing stock on commercial forest land by components, Minnesota, 1976

(In million cubic feet)

Component	All species	Softwood	Hardwood
Timber products	135.0	56.9	78.1
Logging residue	5.1	1.2	3.9
Other removals	53.5	10.7	42.8
Total	193.6	68.8	124.8

This pattern is also reflected in growing-stock removals as a percent of volume for all species in aggregate (table 7). However, certain individual species may have been overcut in some areas of northern Minnesota. For example, more than 6 percent of the jack pine growing stock was removed in 1976 in Carlton, Lake, Koochiching, Roseau, Clearwater, Mahnomen, Aitkin, Otter Tail, Todd, and Morrison Counties. Jack pine may have been overcut in these counties. At the same time, less than 2 percent of the growing stock was removed in Cook, Crow Wing, Hubbard, and Lake of the Woods Counties and none was removed in six counties with a significant volume of jack pine in the Central Hardwood Unit. Removals of less than 2 percent annually may indicate underutilization of the jack pine resource.

These indicators of possible over and underutilization of species should be used cautiously when developing future wood procurement strategy and for making other forest management decisions because (1) sampling errors at the county level may be high for individual species, (2) wood procurement patterns and volumes change from year to year, (3) stand age structure may mask the extent of under or overutilization, and (4) apparent over or undercutting may be a temporary timber management tool to improve the stand structure and species mix.

Table 7.--Timber removals from growing stock on commercial forest land for selected species groups as a percent of growing-stock volume in Minnesota counties, 1976.

County	All species	Jack pine	Spruce	Balsam fir	Aspen	Paper birch	Oak
Aitkin	1.5	7.9	1.4	1.2	3.5	0.8	1.7
Anoka	3.8	--	--	--	--	--	3.7
Becker	0.7	2.3	0.9	1.3	0.5	0.4	0.5
Beltrami	1.6	2.8	2.7	2.8	2.3	1.2	0.6
Benton	2.0	0.0	--	--	--	--	3.3
Big Stone	3.7	--	--	--	--	--	--
Blue Earth	2.6	--	--	--	--	--	2.6
Brown	2.8	--	--	--	--	--	--
Carlton	1.1	12.8	0.4	0.5	2.6	0.9	--
Carver	8.0	--	--	--	--	--	--
Cass	1.1	2.8	0.8	0.7	1.4	0.8	0.7
Chippewa	4.2	--	--	--	--	--	--
Chisago	1.4	0.0	--	--	--	--	0.6
Clay	2.2	--	--	--	--	--	--
Clearwater	1.3	11.5	6.9	2.0	1.1	0.6	0.7
Cook	0.8	1.5	0.9	0.4	1.1	0.3	--
Cottonwood	3.6	--	--	--	--	--	--
Crow Wing	0.9	1.5	--	0.8	1.2	0.4	0.4
Dakota	5.9	--	--	--	--	--	--
Dodge	2.8	--	--	--	--	--	--
Douglas	4.6	--	--	--	--	--	--
Faribault	4.4	--	--	--	--	--	--
Fillmore	3.7	--	--	--	--	--	3.9
Freeborn	3.2	--	--	--	--	--	--
Goodhue	1.6	--	--	--	--	--	1.5
Grant	3.2	--	--	--	--	--	--
Hennepin	8.2	--	--	--	--	--	--
Houston	1.9	--	--	--	--	--	2.4
Hubbard	1.3	1.7	0.7	0.5	1.8	0.8	0.4
Isanti	1.9	0.0	--	--	--	--	2.0
Itasca	1.7	2.6	3.0	2.2	2.4	0.8	1.3
Jackson	3.8	--	--	--	--	--	--
Kanabec	1.8	0.0	--	--	1.5	0.8	1.4
Kandiyohi	2.9	--	--	--	--	--	--
Kittson	1.4	--	--	--	1.3	--	1.7
Koochiching	3.0	7.4	3.7	3.7	4.2	1.0	--
Lac Qui Parle	3.2	--	--	--	--	--	--
Lake	1.2	8.7	2.7	1.2	1.0	0.6	--
Lake of the Woods	2.3	1.9	5.3	1.1	3.2	1.0	--
LeSueur	4.9	--	--	--	--	--	--
Lincoln	3.6	--	--	--	--	--	--
Lyon	3.2	--	--	--	--	--	--
Mahnonmen	2.2	13.3	--	--	2.9	2.4	1.3
Marshall	1.4	--	--	--	1.3	--	1.6
Martin	3.3	--	--	--	--	--	--
McLeod	9.1	--	--	--	--	--	--
Meeker	4.6	--	--	--	--	--	--
Mille Lacs	3.7	0.0	--	--	8.0	1.1	2.1
Morrison	2.5	13.2	--	--	4.0	1.4	2.2
Mower	3.1	--	--	--	--	--	--
Murray	6.1	--	--	--	--	--	--
Nicollet	3.3	--	--	--	--	--	--
Nobles	8.2	--	--	--	--	--	--
Norman	1.7	--	--	--	--	--	--
Olmsted	2.6	--	--	--	--	--	2.0
Otter Tail	1.9	14.4	--	--	1.4	1.5	1.9
Pennington	1.4	--	--	--	1.4	--	--
Pine	1.3	5.8	0.6	1.0	1.4	1.2	1.0
Pipestone	7.6	--	--	--	--	--	--
Polk	1.8	--	--	--	1.4	--	1.5
Pope	3.1	--	--	--	--	--	--
Ramsey	--	--	--	--	--	--	--
Red Lake	1.4	--	--	--	1.3	--	--
Redwood	3.3	--	--	--	--	--	--
Renville	3.2	--	--	--	--	--	--
Rice	7.5	--	--	--	--	--	--
Rock	8.5	--	--	--	--	--	--
Roseau	3.8	7.6	8.3	2.3	3.1	3.6	--
St. Louis	1.6	4.5	1.8	1.0	2.4	0.5	--
Scott	6.3	--	--	--	--	--	--
Sherburne	0.8	0.0	--	--	--	--	0.9
Sibley	2.7	--	--	--	--	--	--
Stearns	2.4	--	--	--	--	--	2.7
Steele	3.2	--	--	--	--	--	--
Stevens	5.5	--	--	--	--	--	--
Swift	3.8	--	--	--	--	--	--
Todd	1.8	28.6	--	--	0.8	1.2	2.7
Traverse	6.9	--	--	--	--	--	--
Wabasha	1.3	--	--	--	--	--	1.7
Wadena	2.0	3.0	--	--	1.2	4.7	0.9
Waseca	3.7	--	--	--	--	--	--
Washington	6.5	--	--	--	--	--	--
Watonwan	4.3	--	--	--	--	--	--
Wilkin	9.8	--	--	--	--	--	--
Winona	1.5	--	--	--	--	--	1.6
Wright	2.9	--	--	--	--	--	3.2
Yellow Medicine	2.8	--	--	--	--	--	--

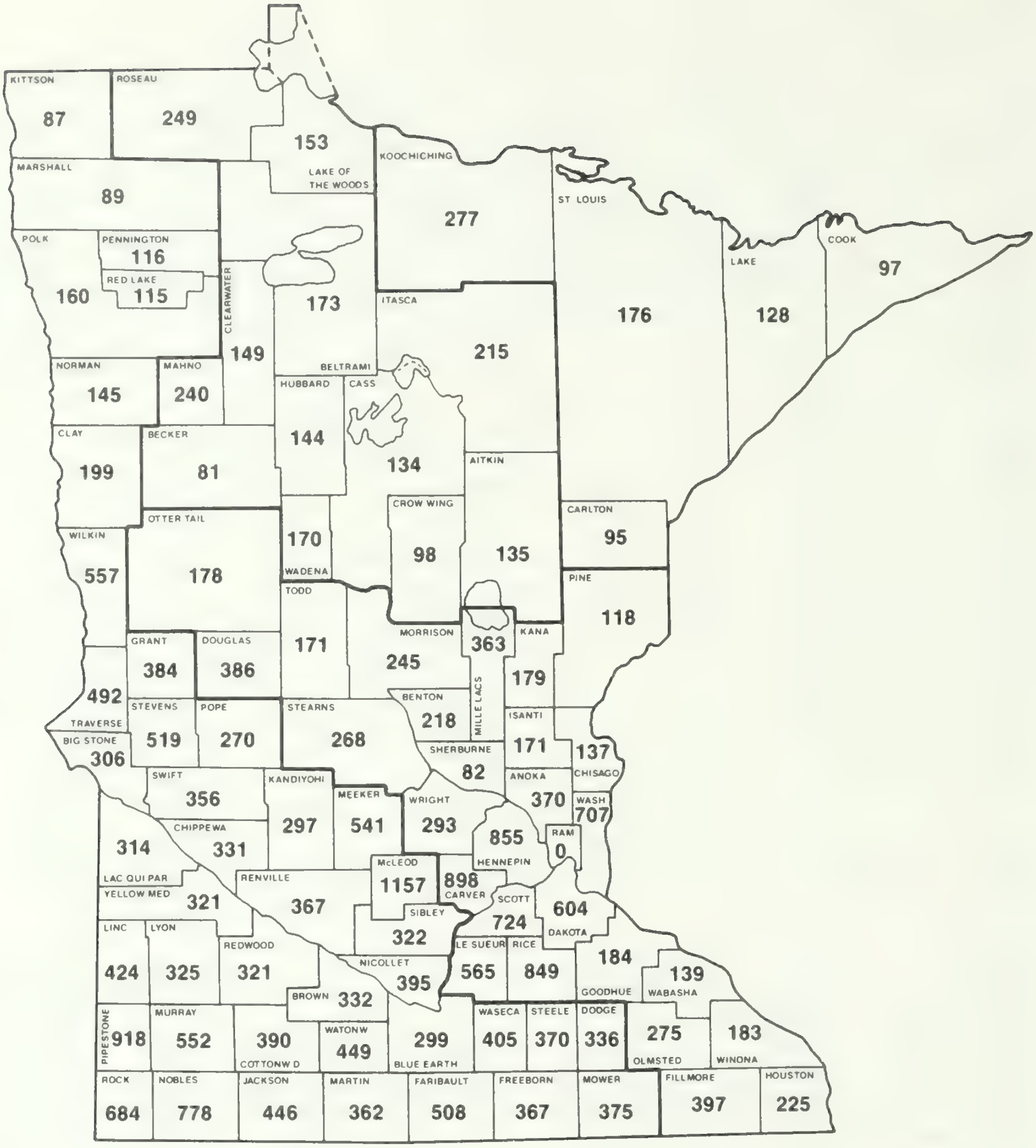

Figure 4.--Cords of timber removals from growing stock on commercial forest land per thousand acres of commercial forest land, Minnesota, 1976

(One cord=79 cubic feet of solid wood fiber.)

With this caution in mind, it appears spruce growing stock may have been overcut in Clearwater, Roseau, Lake of the Woods, and Koochiching Counties and underutilized in adjacent or nearby counties.

Growing stock removal rates for balsam fir are generally lower than for spruce and no county had a removal rate more than 3.7 percent. Thus, overcutting of balsam fir seems less likely than overcutting of spruce.

Aspen growing stock removals were 4 percent or more in Koochiching, Mille Lacs, and Morrison Counties and between 3 and 4 percent in Aitkin, Lake of the Woods, and Roseau Counties. Aspen seems to be underutilized in 13 counties in the western half of northern Minnesota where aspen growing stock removals were under 2 percent in each county in 1976. These counties are in the area near Bemidji where two waferboard plants are under construction. Aspen will be the principal species used in these mills. Other counties in which aspen removals were less than 2 percent were Lake, Cook, Kanabec, and Pine. However, Canadian mills have increased their use of aspen from Cook County since 1976.

Paper birch harvesting could be increased substantially without surpassing a sustained yield. Twelve counties in northeastern and north-central Minnesota had paper birch growing-stock removals of less than 1 percent in 1976 and eight nearby counties had removal rates between 1.0 and 1.5 percent.

Oak removals appear to be below a sustained yield level in the northern third of Minnesota--no county had a removal rate exceeding 2 percent and a seven-county block had a removal rate of less than 1 percent. In central and southeastern counties, removals seemed high in some counties but low in nearby counties, perhaps indicating removals not far from a sustained yield for these areas.

Outlook

Recent forest industry developments include construction of two waferboard plants in Bemidji and one in Cook in St. Louis County and a major expansion of the waferboard plant in Grand Rapids. A $50 million pulp mill expansion at Sartell has been announced. Other companies have recently expanded their operations or are considering further expansions. Overall, the future for Minnesota's forest industry appears bright.

MINNESOTA'S FOREST RESOURCE, 1977

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The following comments on Minnesota's forests present only the highlights of the 1977 survey. I have reduced the many long tables of information generated from the survey to a few, manageable ones.

Area

Minnesota's forest land in 1962, 18.4 million acres, represented 36 percent of the State's total land area. In 1977 the 16.7 million acres of forest accounted for 33 percent of the total. Commercial forest land dipped from 15.4 to 13.7 million acres between surveys, a decline of 11 percent. Unproductive forest dropped by 28 percent between surveys and productive-reserved forest increased 2½ times due to the creation of the Voyageurs National Park and the expansion of the reserved portion of the Boundary Waters Canoe Area.

Statistics for 1962 have been adjusted from those published after the 1962 survey to conform to 1977 statistics because of changes in the methods of determining unproductive forest and wooded pasture land between surveys.

What happened to the commercial forest land that was lost between 1962 and 1977? The largest portion (nearly 700 thousand acres) was placed in productive-reserved status as a result of legislation at the national level. Roughly 400 thousand acres were converted to urban and related uses and another 400 thousand acres were converted to cropland. Nearly 200 thousand acres were converted to other uses and to marsh and about 100 thousand acres were converted to improved pasture.

The Aspen-Birch and Northern Pine Units contain the bulk of the State's forest (table 1). The Northern Pine Unit boasts slightly more commercial forest, but the Aspen-Birch Unit contains most of Minnesota's productive-reserved forest.

Table 1.--Area of forest land by Forest Survey Unit, Minnesota, 1977

(In thousand acres)

Forest land	Forest Survey Unit All units	 Aspen-Birch	 Northern Pine	 Central Hardwood	 Prairie
Commercial	13,695.1	5,451.4	5,758.4	1,951.1	534.2
Productive-reserved	1,178.6	1,050.6	46.9	72.4	8.7
Unproductive	1,835.5	969.8	706.9	120.2	38.6
Total	16,709.2	7,471.8	6,512.2	2,143.7	581.5

The aspen-birch forest type dominates the State's commercial forest with 50 percent of the area. The aspen type alone accounts for 39 percent of the area. As shown in the following tabulation, the 6.6 million acres of aspen-birch type in 1962 increased slightly to 6.8 million in 1977.

Forest type	Commercial forest land area 1962	 1977
	(Thousand acres)	
White-red-jack pine	1,284.6	816.9
Spruce-fir	2,921.7	2,944.1
Oak-hickory	1,022.7	893.9
Elm-ash-cottonwood	1,286.4	738.1
Maple-basswood	1,004.3	1,283.9
Aspen-birch	6,642.4	6,848.8
Nonstocked areas	1,249.7	169.4
Total	15,411.8	13,695.1

The big drop in nonstocked area does not represent actual physical change but is due primarily to use of a more sophisticated technique to determine stocking class than was used in 1962. The maple-basswood type increased in area more than any other type -- 28 percent. The white-red-jack pine type fell by 36 percent, largely because of a sharp drop in jack pine area.

Public agencies own or administer 54 percent of the State's commercial forest, and private owners account for the other 46 percent (table 2). Nonindustrial private parties own 41 percent of the total area, clearly making them the owner group with the greatest potential impact on Minnesota's forest resource. Farmers alone own 25 percent of the commercial forest.

Poletimber stands grow on 51 percent, sapling and seedling stands occupy 25 percent, and sawtimber stands grow on 23 percent of the total area, (table 3). It is not possible to accurately adjust the 1962 areas of each stand-size class in order to compare them with the 1977 areas, but it is obvious that the area of sawtimber stands increased substantially between surveys as waves of trees grew out of poletimber size in the continuing maturation of the State's forests. Sawtimber stands are most prevalent in the Central Hardwoods Unit where they represent 40 percent of total area.

Table 2.--Area of commercial forest land by ownership class and Forest Survey Unit, Minnesota, 1977

(In thousand acres)

	Forest Survey Unit				
Ownership class	All units	Aspen-Birch	Northern Pine	Central Hardwoods	Prairie
National Forest	1,715	1,153	562	--	--
Other Federal	621	126	461	25	9
State	2,650	1,132	1,229	244	45
County and Municipal	2,342	1,186	1,097	59	--
Forest Industry	772	535	234	--	3
Farmer	3,404	544	1,322	1,142	396
Other Private	2,191	775	854	481	81
Total	13,695	5,451	5,759	1,951	534

Stands aged 30 to 60 years clearly occupy the largest area as shown in the following tabulation. These stands originated from 1917 to 1947 and represent, among other things, the results of a vigorous fire protection program, an active tree planting program, and a general awareness that the old ways of high-grading the woods and letting the slash burn were no longer acceptable.

Stand-age class	Commercial forest land area
(Years)	(Thousand acres)
1-10	1,210
11-20	1,129
21-30	1,064
31-40	1,772
41-50	2,620
51-60	2,274
61-70	1,278
71-80	819
81-90	568
91-100	503
101-120	279
121-140	174
141+	5
Total	13,695

Table 3.--Area of commercial forest land by stand-size class and Forest Survey Unit, Minnesota, 1977

(In thousand acres)

Forest Survey Unit	Stand-size class				
	All	Sawtimber	Poletimber	Sapling and seedling	Non-stocked areas
Aspen-Birch	5,451	943	2,847	1,596	65
Northern Pine	5,759	1,226	3,082	1,380	71
Central Hardwoods	1,951	786	848	290	27
Prairie	534	180	179	169	6
Total	13,695	3,135	6,956	3,435	169

Seventy-nine percent of the commercial forest is at least medium-stocked with trees (table 4). Poorly stocked stands account for 20 percent of the area, and nonstocked areas account for 1 percent. More than one-fourth of all sapling and seedling stands are poorly stocked or nonstocked.

Volume

Volume of growing stock on commercial forest land increased 21 percent between surveys--from 9.4 to 11.5 billion cubic feet:

Species group	Growing-stock volume	
	1962	1977
	(Million cubic feet)	
Softwoods	3,384	3,477
Hardwoods	6,060	7,977
Total	9,444	11,454

Table 4.--Area of commercial forest land by stocking class of growing-stock trees and stand-size class, Minnesota, 1977

(In thousand acres)

Stocking class	Stand-size class				
	All	Sawtimber	Poletimber	Sapling and seedling	Nonstocked areas
Nonstocked	166	2	7	8	149
Poorly stocked	2,725	614	1,214	897	--
Medium stocked	7,481	1,734	3,924	1,803	20
Well stocked	3,006	716	1,660	630	--
Overstocked	317	69	151	97	--
Total	13,695	3,135	6,956	3,435	169

Softwoods volume increased a modest 3 percent, but hardwoods volume jumped 32 percent during the 15 year interim.

As shown below, sawtimber volume on commercial forest land made a 65 percent gain between surveys--from 14.9 to 24.6 billion board feet:

Species group	Sawtimber volume 1962	Sawtimber volume 1977
	(Million board feet)	
Softwoods	6,133	8,530
Hardwoods	8,742	16,077
Total	14,875	24,607

Softwood sawtimber volume increased 39 percent, but hardwood volume spurted 84 percent.

These volume gains reflect the maturing of Minnesota's forests, further shown by the average growing-stock volume per acre that increased from 613 to 836 cubic feet (7.8 to 10.6 cords) between surveys.

In addition to the 11.5 billion cubic feet of growing stock, there are 1.2 billion of rough and rotten trees, 0.2 billion of short-log cull trees, and 0.1 billion of salvable dead trees (table 5). The total volume of timber in all classes, then, is 13.0 billion cubic feet.

Table 5.--Net volume of timber on commercial forest land by class of timber and softwoods and hardwoods, Minnesota, 1977

(In million cubic feet)

Class of timber	All species	Softwoods	Hardwoods
Growing stock:			
Sawtimber	4,732	1,719	3,013
Poletimber	6,722	1,758	4,964
Total growing stock	11,454	3,477	7,977
Rough and rotten cull	1,207	179	1,028
Short-log cull	185	27	158
Salvable dead	107	48	59
All classes	12,953	3,731	9,222

Five species--aspen, paper birch, balsam fir, spruce, and jack pine--account for three-fifths of the growing-stock volume in the State. Aspen is the most abundant species with 30 percent of the volume. Its volume increased by 22 percent between surveys. Paper birch and balsam fir volumes increased by 51 percent and 17 percent, respectively, but spruce and jack pine volumes declined 12 and 19 percent, respectively, between 1962 and 1977.

The bulk of the growing-stock volume is in trees 12 inches or less in diameter (table 6). This is largely because 85 percent of the aspen volume is in those diameter classes.

Nonindustrial private parties own 46 percent of the hardwood growing-stock volume but only 22 percent of the softwood volume (table 7). One half of the softwood volume is almost equally divided between National Forest and State land.

Almost all (98 percent) of the softwood growing-stock volume is in the Aspen-Birch and Northern Pine Units (table 8). Hardwood volume is largest in the Northern Pine Unit (44 percent of the total) with smaller volumes in the Aspen-Birch (33 percent), Central Hardwoods (18 percent), and Prairie (5 percent) Units.

Table 6.--Net volume of growing stock on commercial forest land by softwoods and hardwoods and diameter class, Minnesota, 1977

(In million cubic feet)

Diameter class (Inches at breast height)	All species	Softwoods	Hardwoods
6	2,164.4	881.8	1,282.6
8	2,755.9	876.6	1,879.3
10	2,438.7	637.2	1,801.5
12	1,672.4	397.6	1,274.8
14	972.5	234.1	738.4
16	592.0	169.9	422.1
18	348.1	119.4	228.7
20	191.0	62.4	128.6
22	122.9	47.1	75.8
24-28	144.9	44.0	100.9
30-38	39.3	6.6	32.7
40+	11.9	0.3	11.6
Total	11,454.0	3,477.0	7,977.0

Table 7.--Net volume of growing stock on commercial forest land by ownership class and softwoods and hardwoods, Minnesota, 1977

(In million cubic feet)

Ownership class	All species	Softwoods	Hardwoods
National Forest	1,871.1	871.1	1,000.0
Bureau of Land Management	37.4	22.8	14.6
Indian	374.6	136.6	238.0
Misc. federal	96.6	20.2	76.4
State	1,942.1	818.2	1,123.9
County and municipal	2,012.3	566.7	1,445.6
Forest industry	636.0	265.0	371.0
Farmer	2,706.2	383.6	2,322.6
Miscellaneous private	1,777.7	392.8	1,384.9
Total	11,454.0	3,477.0	7,977.0

Table 8.--Net volume of growing stock on commercial forest land by softwoods and hardwoods and Forest Survey Unit, Minnesota, 1977

(In million cubic feet)

Forest Survey Unit	All species	Softwoods	Hardwoods
Aspen-Birch	4,522.1	1,888.9	2,633.2
Northern Pine	5,022.9	1,509.5	3,513.4
Central Hardwood	1,546.8	76.1	1,470.7
Prairie	362.2	2.5	359.7
Total	11,454.0	3,477.0	7,977.0

A look at the volume of the State's important aspen resource by stand-age classes reveals the same bulge in the 30 to 60 year classes that exists for the area of commercial forest land by stand-age. Recommended rotation age for aspen in the Lake States varies with site index and end product. Generally, aspen on low sites (site index 50 and less) managed for fiber production should be harvested at about age 35 and aspen on high sites (site index 70 +) managed for sawtimber should be harvested at about age 60.[1/] In many areas, low site index aspen deteriorates earlier than high site aspen and should be harvested earlier. As seen in the following tabulation, a large volume of aspen exists in stands more than 60 years old, so large losses are probably occurring.

[1/] Perala, Donald A. 1977. Manager's handbook for aspen in the North Central States. U.S. Dep. Agric. For. Serv. General Technical Report NC-36 , 30 p. U.S. Dep. Agric. For. Serv., North Central Forest Experiment Station, St. Paul, MN.

Stand-age class	Volume of aspen
(Years)	(Million cubic feet)
1-10	159.2
11-20	149.7
21-30	250.3
31-40	816.6
41-50	1,443.0
51-60	1,151.1
61-70	472.6
71-80	144.1
81-90	68.1
91-100	20.9
101-120	3.8
121-140	2.5
141+	--
All classes	4,681.9

Nearly 70 percent of the sawtimber volume is in trees with a butt log of Grade 3 (table 9). The proportion of sawtimber volume in the higher grades (1 and 2) is substantially higher for hardwoods than for softwoods.

Table 9.--Net volume of sawtimber on commercial forest land by softwoods and hardwoods and butt log-grade class, Minnesota, 1977

(In million board feet[1/])

Butt log grade	All species	Softwoods	Hardwoods
1	1,756.5	533.4	1,223.1
2	5,039.0	841.8	4,197.2
3	16,919.3	7,128.0	9,791.3
Tie and timber	892.4	27.4	865.0
All grades	24,607.2	8,530.6	16,076.6

[1/] International 1/4-inch rule.

Growth

Net annual growth of growing stock declined from 364 to 349 million cubic feet between surveys--a 4 percent drop:

Species	Growing-stock net annual growth 1962	Growing-stock net annual growth 1976
	(Thousand cubic feet)	
Softwoods	106,789	119,781
Hardwoods	257,420	229,139
All species	364,209	348,920

Softwood growth increased by 12 percent but hardwood growth fell by 11 percent.

The growth rate was 3.0 percent of inventory in 1976 and 3.9 percent in 1962. The 1976 softwood growth rate (3.4 percent) was higher than the hardwood rate (2.9 percent).

Practically all of the softwood growth volume is in the Aspen-Birch and Northern Pine Units (table 10). Although the Northern Pine Unit accounts for the largest share of the hardwood growth, the hardwood growth rate is highest in the Central Hardwood Unit (4.0 percent).

Mortality

Mortality of growing stock amounted to 142 million cubic feet in 1976 or 1 percent of inventory. Softwoods accounted for 34 million and hardwoods for 108 million cubic feet of mortality. Cause of mortality differed significantly by softwoods and hardwoods (table 11).

Table 10.--Net annual growth of growing stock on commercial forest land by softwoods and hardwoods and Forest Survey Unit, Minnesota, 1977

(In thousand cubic feet)

Forest Survey Unit	All species	Softwoods	Hardwoods
Aspen-Birch	114,899	56,982	57,917
Northern Pine	159,792	59,123	100,669
Central Hardwood	62,295	3,562	58,733
Prairie	11,934	114	11,820
All units	348,920	119,781	229,139

Table 11.--Annual mortality of growing stock on commercial forest land by softwoods and hardwoods and cause, Minnesota, 1976

(In thousand cubic feet)

Cause	All species	Softwoods	Hardwoods
Insects	6,767	6,075	692
Disease	80,875	14,541	66,334
Fire	7,685	505	7,180
Animals	3,507	464	3,043
Weather	23,863	4,700	19,163
Suppression	19	19	--
Logging	787	132	655
Timber stand improvement	703	--	703
Land clearing	45	45	--
Unknown and other	17,290	7,247	10,043
All causes	141,541	33,728	107,813

Projections

Projections of Minnesota's timber resource were made using the Forest Service computer program, Timber Resource Analysis System. Two sets of projections were made. A continuation of recent levels of timber removals (low removals option) was assumed for one and a higher level of removals (high removals option) was assumed for the other. Separate projections were made for softwoods and for hardwoods.

Assumptions common to both low and high options were: (1) the total area of commercial forest land will decline at an annual rate of 0.31 percent, (2) radial growth will decline in relation to the increase in the basal area per acre of trees, (3) the intensity of forest management will continue at the rate indicated by recent trends, and (4) the volume of "other" removals will drop during the period as more of these trees are utilized for products.

The low removals option projection assumed that total timber removals will increase at an average annual rate of 2.7 percent (5.4 million cubic feet). Total growth is projected to be higher than removals throughout the 30-year period, but to turn down and approach removals after about 1987. Inventory increases are projected to diminish after growth turns down and to almost flatten out by the end of the period (table 12).

The high option projection assumed that total removals will increase at an average annual rate of 4.8 percent (9.6 million cubic feet). Growth is projected to be higher than removals until about 2001 when removals outstrip growth and remain higher than growth for the remainder of the period. Inventory peaks in 2001 at 14.3 billion cubic feet then declines to 14.0 billion by 2007 (table 12).

Table 12.--Removals, net annual growth, and inventory of growing stock on commercial forest land, Minnesota, 1977 and low removals option and high removals option projections to 2007

(In million cubic feet)

LOW REMOVALS OPTION

	Removals			Growth			Inventory		
Year	All species	Softwoods	Hardwoods	All species	Softwoods	Hardwoods	All species	Softwoods	Hardwoods
1977	198.4	70.7	127.7	348.9	119.8	229.1	11,454.0	3,477.0	7,977.0
1987	251.8	91.7	160.1	431.7	128.6	303.1	13,229.6	3,923.0	9,306.6
1997	307.6	112.8	194.8	415.7	126.4	289.3	14,698.0	4,174.7	10,523.3
2007	359.8	127.5	232.3	375.3	121.5	253.8	15,287.2	4,205.3	11,081.9

HIGH REMOVALS OPTION

	Removals			Growth			Inventory		
Year	All species	Softwoods	Hardwoods	All species	Softwoods	Hardwoods	All species	Softwoods	Hardwoods
1977	199.1	71.1	128.0	348.9	119.8	229.1	11,454.0	3,477.0	7,977.0
1987	270.3	98.5	171.8	432.1	128.5	303.6	13,148.8	3,889.8	9,259.0
1997	371.6	132.9	238.7	422.0	126.7	295.3	14,237.4	4,006.8	10,230.6
2007	485.7	166.1	319.6	392.7	122.8	269.9	13,995.4	3,750.2	10,245.2

NEW FEATURES OF THE 1977

MINNESOTA INVENTORY

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The Minnesota Forest Inventory team collected new data and used new computational methods to provide a more detailed analysis of Minnesota's timber resource in 1977. This new data includes information on insects and diseases, biomass, operability, and treatment opportunities. A new system to simplify retrieval of this data from the computer is also being used.

Insects and Disease

The field crews worked year-round but most insect and some disease damage is much easier to detect during certain times of the year than at other times. Disease damage was recorded whenever the disease was present and insect damage was recorded only when it was extensive. Because most insect damage is difficult to identify year-round, poplar borer was the only specific insect damage recorded. Diseases were identified and recorded as follows:

Disease	Tree species
Hypoxylon	Aspen
Phellinus tremulae	Aspen
Other cankers	Aspen
Scleroderris	Red and jack pine
Sirococcus	Red pine
Blister rust	White pine
Dwarf mistletoe	Black spruce
Annual cankers	Hardwoods excluding aspen
Other cankers	Hardwoods excluding aspen

The percent of commercial forest land in the aspen type in Aitkin County, Minnesota, with incidence of Phellinus tremulae and hypoxylon canker is an example of the type of data that can be compiled from the data base (figure 1).

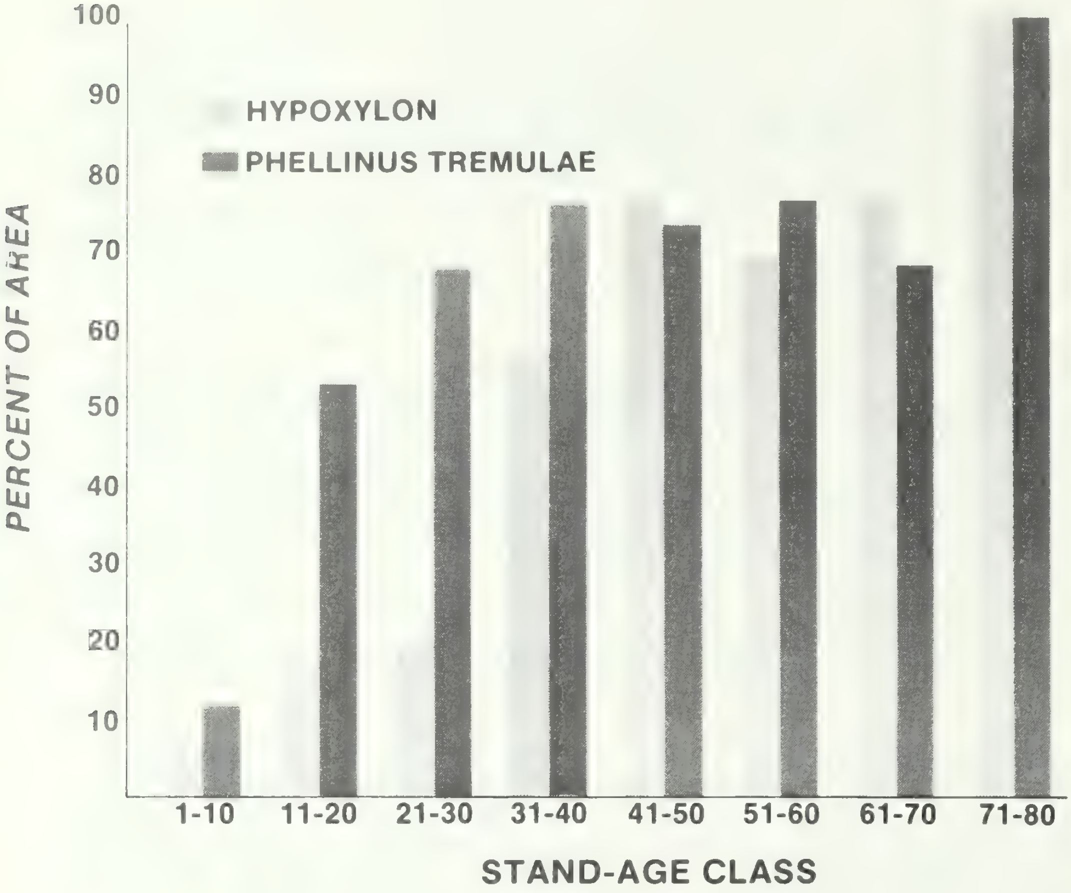

Figure 1. Aspen forest type with incidence of Hypoxylon and Phellinus tremulae on aspen growing stock, Aitkin County, Minnesota, 1977

We found that all aspen stands more than 70 years old in Aitkin County contain both hypoxylon and Phellinus and that Phellinus is more prevalent in younger stands than hypoxylon. Other examples of disease information compiled for Aitkin county are:

(1) 23 percent of the white pine growing-stock volume is infected with blister rust,

(2) 4 percent of the black spruce growing-stock volume is infected with dwarf mistletoe, and

(3) no red and jack pine are infected with Scleroderris or Sirococcus.

Biomass

An increase in demand for wood energy and fiber has increased interest in whole-tree utilization and therefore in total biomass of the State's forests. In the past, forest inventories only included volume information based on the net volume of wood in the traditional merchantable bole, which only accounts for a little more than a third of the total biomass. Today more complete utilization is taking place so biomass is presented as green tons of wood, bark, and foliage in all live tree boles, tops, and limbs for trees 1 inch diameter breast height (d.b.h.) and larger. The distribution of biomass among these components is different for hardwoods and softwoods. In Aitkin County 41 percent of the softwood biomass and 20 percent of the hardwood biomass is in trees 1-to 5-inches d.b.h. (table 1).

Table 1.--All live tree biomass by component for softwoods and hardwoods, Aitkin County, Minnesota, 1977

(In green tons)

Component	Softwoods	Hardwoods	Total
Growing-stock boles	1,867,673	11,689,202	13,556,875
Growing-stock tops and limbs	928,108	5,758,833	6,686,941
Cull boles	242,041	2,598,310	2,840,351
Cull tops and limbs	170,200	1,724,280	1,894,480
1 to 5 inch trees	2,243,779	5,244,010	7,487,789
All components	5,451,801	27,014,635	32,466,436

Operability

Traditionally, Resources Evaluation personnel have concentrated their efforts on reporting commercial forest area, timber volume, growth, and removals. Statistics on some variables affecting stand operability were available but only in a fragmented form. Analysts are now working on a study of the operability and location of Minnesota's timber resource.

Some plot variables being used in this study include physiographic class, slope, site class, stand area and volume, distance to road, and average stand d.b.h. These variables reflect the total value of timber and the cost of removal and will be used to create operability classes. These classes will then be used to analyze the forest resource. In addition, the Universal Transverse Mercator coordinates of the plots are being determined which will allow an analysis of the operability of stands within a given distance of various locations in the State.

Treatment Opportunities

One of the objectives of the Forest and Rangeland Renewable Resources Planning Act of 1974 is the evaluation of renewable resource investment opportunities. Representatives from forest industry and the Minnesota Department of Natural Resources jointly identified the harvest criteria for each forest type in Minnesota. Station personnel then used the Forest Resource Evaluation Program (FREP) to select plots needing harvest or other treatment. FREP simulated the treatments and determined the volumes removed during these treatments.

Three treatment categories were identified: (1) harvest (2) timber stand improvement (thinning and cull tree removal), and (3) stand conversion or restocking. Given the assumptions and criteria used in the analysis, 37 percent of Minnesota's commercial forest land could benefit from one of these treatments during the decade 1977-1986. However, this figure is a biological maximum only, so forest managers and planners must temper these findings to fit the resource conditions in their areas.

Management Information Systems

In Minnesota a system--called System 2000-- is being tested that allows information retrieval without writing computer programs. Data can be retrieved in tabular form or used as input for other programs that present the data in graphic form. This is the only State in the Nation to have its forest inventory statistics summarized and loaded onto a commercially available data base management system.

HOW THE STATE OF MINNESOTA USES INVENTORY INFORMATION

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The assigned topic for this presentation is "How the State of Minnesota Uses Inventory Information." A more appropriate title might be "How the State of Minnesota intends to Use Inventory Information for Forest Resources Planning". I will begin with brief descriptions of the State's inventory systems and how the data has been used in the past. I will then describe how inventory data might be used in future planning programs.

The Department of Natural Resources (DNR) refers to its forest resources inventories as Phase I and Phase II. Phase I is the forest survey carried out in cooperation with the North Central Forest Experiment Station. It provides statistical estimates of the extent, condition, volume of growing stock, growth, and depletions for all forest lands in Minnesota. Phase II data is based on compartment examinations of State-and county-administered forest lands. Phase II inventory information can be retrieved in map or tabular form for individual stands. It can also be summarized for each State Forest, county, administrative district or other geographic area.

The Long Range Plan for the Forest Management Program (MN-DNR, 1977) is an example of the use of forest resource information to project supply and demand trends and to develop long term management proposals. Inventory information is also used to develop State Park vegetation management plans.

The DNR has been using inventory information to prepare timber management plans for a number of years. The additional information collected during Phase II and enhanced data manipulation capabilities will allow the DNR to prepare more detailed and sophisticated timber management plans in the future. Bruce ZumBahlen's description of the use of inventory data to calculate allowable cuts is presented in these Proceedings.

The use of inventory information, however, goes far beyond day-to-day applications for short term management. Forest resource inventory information must be the data base for comprehensive resource management plans in which long range goals and objectives are set. Forest inventories provide the crucial information required to make the management decisions needed to improve the productivity of our forest lands.

As previously stated, the Department of Natural Resources has used inventory information to prepare timber management plans for State Forest districts. In light of current demands on our forest resources, however, these plans are not adequate to ensure a continuous flow of those resources and other services from State-administered lands. The Minnesota Department of Natural Resources is charged with the management of forest resources on nearly 5 million acres of land in the State. In addition, the Department administers a number of programs which provide incentives for forest management on private lands.

There are a number of issues which are of concern to forest management because they affect the long term availability of our forest resources. The most important of those issues are summarized here.

(1) Demands for timber and other forest resources are increasing steadily while the commercial forest land base in Minnesota is decreasing.

(2) Demands on the State's forest resources are expected to increase at a rate which will exceed the ability of the forests to satisfy those demands at the present level of management intensity.

(3) There are a number of current land use issues which affect or may affect the availability of forest resources. Among these are recreational land reservations, utility corridors, sewage sludge disposal, hazardous waste disposal and the rapidly increasing demand for fuelwood.

(4) There are ongoing comprehensive planning programs for facilities which may affect forest resources but which, because of their scope, do not take all of the forest resources into account. Some of these programs are for State Parks, wild and scenic rivers, State trails and water access sites.

These and other important issues have been under investigation by the Governor, the Legislature and the Department of Natural Resources. There is an obvious and critical need to improve and intensify the management of our forest resources. There are however, many serious questions regarding the best way to accomplish that goal. Two of those questions involve (a) the best method of providing the optimum mix of forest resource products; and (b) alternative methods of funding the improvement and intensification of forest resources management.

In an attempt to deal with these questions and the myriad of other issues and influences affecting forest management, the DNR has proposed a comprehensive forest resources planning program. That program is discussed in two documents available from the DNR's Division of Forestry and summarized here. The two documents are, Forest Resources Planning; an Analysis and Proposal, and Minnesota Forest Resources Plan - Volume 1: Planning Concept.

The DNR currently has statutory authority to develop forest plans (MS 86A.07; 86A.09 and MS 89.01, Subd 4) but has not been adequately funded or staffed for this activity.

The planning program proposed by the DNR will be aimed at satisfying the goal of improving and intensifying management of all forest resources in order to meet current and future demands. The program will include development of (1) a Minnesota Forest Resources Plan (MFRP) using the federal Resource Planning Act (RPA) where applicable as a model and (2) management plans for individual State Forest units.

Among the important objectives of the forest planning program are:

- organize resource inventory data into a system usable in forest management decision making;
- address and resolve issues pertaining to forest management;
- provide a consistent and systematic process for decision making;
- coordinate DNR forest planning efforts with those of federal, State and local agencies, private industries and associations.

The MFRP will contain a resource assessment which will examine what forest lands are producing and what they are capable of producing. A program of management will be developed using the assessment as the information base. The forest planning process is not a one-time effort. The assessment and its resulting program will be updated and revised at regular intervals.

Public involvement will play an important role in the forest planning program. One method of obtaining necessary information from a concerned public may be the formation of a task force composed of key people. Those people would serve to provide technical assistance as well as to monitor the planning process.

In order to accelerate forest management and to increase growth and yield, funding will be necessary from the State Legislature and the Federal Government. Funding will not be forthcoming without adequate planning which is accomplished with public involvement. The DNR is proposing a major forest planning program for consideration by the Governor and the Legislature, through the Legislative Committee on Minnesota Resources. The program should begin not later than July 1, 1981.

The two previously mentioned documents which discuss forest planning are available upon request from the DNR. They explain the forest planning proposal in detail and suggest several funding alternatives for the program.

The DNR has contacted a number of agencies and organizations regarding a State Forest planning program. Those who have expressed interest and who support the concept of State Forest planning are listed here.

U.S. Forest Service
State Planning Agency
State Department of Agriculture
Environmental Quality Board
Minnesota Association of Regional Commissions
University of Minnesota; College of Forestry
Timber Producers Association
Minnesota Forest Industries Information Council
Minnesota Association of Snowmobilers

A number of equally important forest user groups remain to be contacted. Support for the comprehensive forest planning proposal will be sought from all interested parties.

All citizens who make use of our valuable forest resources can benefit from a comprehensive forest planning program because the goal of that program will be to improve the resources and to ensure that they are available in a continuing supply.

For additional information, please contact the DNR Division of Forestry.

USE OF PHASE I INVENTORY INFORMATION IN DETERMINING ALLOWABLE CUTS FOR STATE LANDS

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In the absence of an intensive forest inventory on State Lands (phase II), the completion of the Statewide inventory (phase I) enabled the Minnesota Department of Natural Resources to redetermine allowable cuts as part of the overall effort to intensify forest managmeent on State lands. The economic rotation ages used in determining the recommended harvests for State lands are planning tools (table 1). They do not require every stand in a particular cover type to be harvested at a particular age. Site index and other factors would also be considered.

Table 1.--Recommended harvest by cover type on State land, 1980-1990

Cover type	Total cover type acreage	Rotation age	Acres per year
	(acres)	(years)	
Aspen	842,500	40	20,390
Birch	129,500	40	3,250
Balm of Gilead	139,200	40	3,340
Lowland hardwoods	123,000	90	1,320
Northern hardwoods	117,400	80	1,470
Oak	65,600	80	820
Spruce-fir	22,500	60	4,320
	197,700	50	
*Jack pine	93,600	50	1,726
White pine/	2,600	100	220
Norway pine	23,500		
*Black spruce	429,000	90	4,700
Tamarack	223,800	90	2,470
White cedar	202,200	90	2,000

*Until FY 1983, annual recommended harvest for jack pine will be 2,700 acres, black spruce will be 6,120 acres. Starting in FY 1983, the recommended harvest for these two types will decline to the above figures by 1990.

Part of the solution to offset the loss of softwoods caused by wilderness designations (BWCA) was to accelerate the harvest of mature stands on State lands. For a period of time, this will cause over-cutting in the jack pine and black spruce types. However, beginning in FY 1983 (July 1, 1982), the jack pine and black spruce allowable cuts will be reduced annually until they approximate their recommended levels in 1990. (fig. 1).

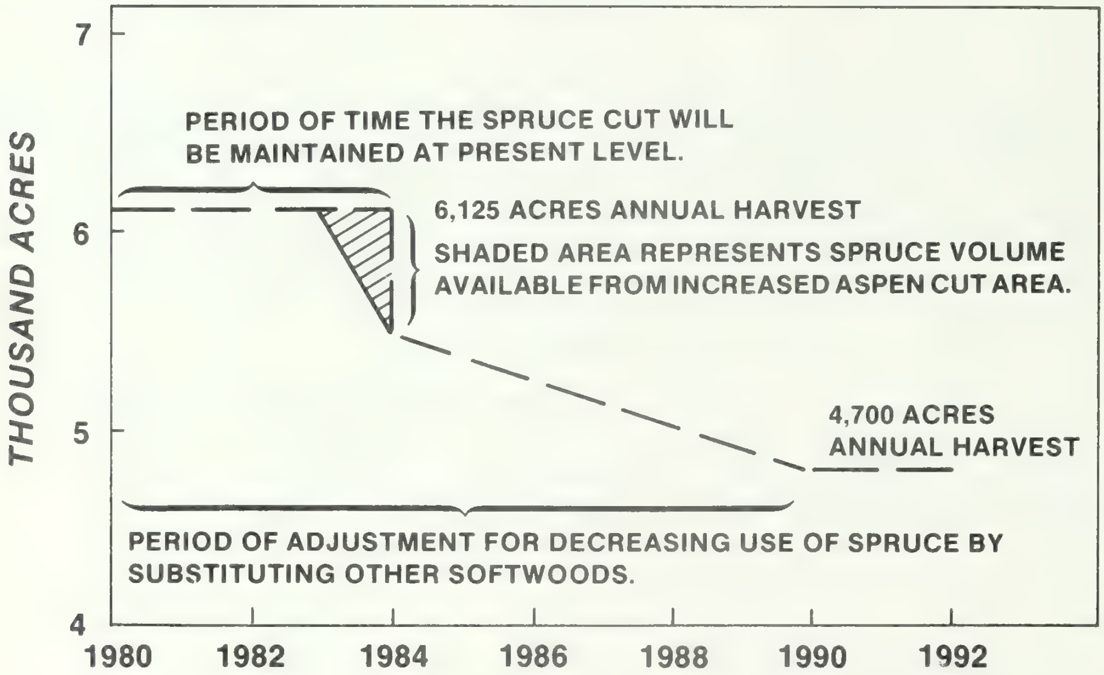


Figure 1.--Recommended harvest of black spruce type on State land in acres to year 1992.

The decline in the jack pine and black spruce allowable cuts was planned to coincide with the start-up of new industries and expansions that would utilize more of the aspen resource. The increased level of aspen harvest would make available the softwoods that are mixed in with the aspen, thus helping to replace the declining harvest in the pine and spruce types.

In order for the Statewide program to be implemented in the field, the following procedure was devised to allocate the allowable cut:

1. Compile Statewide cover type acreages from present District or State Forest management plans (as revised by Phase II).
2. Apportion the Phase I recommended harvest to each Area by comparing the Areas' cover type acreages to Statewide totals (to determine regulated cuts).
3. Adjust the regulated cuts by comparing the average age and acreage of cover types in a County/Area to their Statewide average age and acreage (to determine allowable cuts).
4. Each Area may adjust their District allowable cuts within their Area allowable cuts in order to meet the local situations.
5. Annually, the allowable cut will be revised to reflect Phase I recommended harvests and the completion of Phase II inventory projects.

Example: *Black spruce cover type

Statewide Totals			Area				
Phase I- Recommended Harvest by FY		Dist./Forest Mgt. Plans	Mgmt. Plans	Percent of Total Cover Type	Reg. Cut	Age Factor	Allow. Cut
1980-1982	6,125 ac.	475,000 ac.	30,000 ac.	.0632	387 ac.	.931	360 ac.
1983	5,500	460,000	29,000	.0630	347	.931	323
1984	5,365	450,000	29,500	.0656	352	.931	327
1985	5,230						
1986	5,100						
1987	4,970						
1988	4,835						
1989	4,700						

*Estimated for this example only. Subject to change as Phase II Inventory is completed. At some point in time, we should have sufficient data from our Phase II Inventory to regulate the allowable cuts on that basis alone.

This is how it would work:

> If an Area has 5 percent of the total jack pine cover type Statewide, it would receive an initial allocation of 5 percent of the Statewide recommended harvest for that year. In turn, this acreage would be adjusted by comparing the average age and acreage in the Area to the Statewide average age and acreage. Thus, if jack pine in an Area averaged 20 percent older than jack pine Statewide, that 5 percent would be increased by 20 percent, yielding 6 percent of the Statewide recommended harvest.

By using this procedure, we are attempting to bring into balance the Statewide distribution of age classes of a cover type so that they will be similar in each Area.

HOW THE UNIVERSITY OF MINNESOTA, COLLEGE OF FORESTRY USES INVENTORY INFORMATION

Alan R. Ek and Dietmar W. Rose, Professors
College of Forestry
University of Minnesota

Introduction

College of Forestry staff are frequent users of forest survey information. Such information serves as essential background for organizing and directing instructional and research efforts. The close physical and operational relationship that College staff have with North Central Forest Experiment Station staff frequently allows for greater opportunities in use of survey data than for other groups. Both the College and North Central Forest Experiment Station utilize the same University of Minnesota computer facilities and many of the same software packages, particularly the System 2000 data base management package, on which much of the survey data is resident. College staff also have an inside track on the availability and utility of National Forest survey efforts and associated data by virtue of undergraduate and graduate training efforts. Many North Central staff, at one time or another, have been students under the guidance of College of Forestry faculty. Because of these factors, College of Forestry staff have been effective users of the 1977 survey data we are discussing today for a period of over two years.

Our intent here is to describe some of the uses we make of inventory data for research and what might be called direct project use. The latter refers to use of the data to meet the objectives of projects sponsored by a variety of public or private groups. The emphasis for most of these projects is on economic analyses. In view of our long and frequent usage of survey data, we will also attempt to describe our experience in terms of shortcomings and opportunities we see for the forest survey, its users, and the data base.

Measurements and Inventory Research

The College has traditionally been involved in much measurement and inventory research associated with the forest survey. Recent efforts have concentrated primarily on the assessment of sampling design alternatives, particularly on alternative approaches to developing more information from the data base more efficiently. Such efforts can be broken into four categories:

1. James-Stein and empirical Bayes approaches to the use of prior information for volume and acreage estimation.

This is a research effort geared to obtaining better county level statistics. James-Stein estimation and empirical Bayes approaches are both probability based techniques for utilizing prior or existing information to improve the efficiency and accuracy of estimates. As an example, traditional procedure leads to the estimate of quantities in Itasca County based only upon the data in that county. James-Stein and empirical Bayes approaches allow us to use data from surrounding counties to improve estimates for a particular county. Gains in precision of 20 to 50 percent are common. As an alternative to increasing precision, fieldwork for the maintenance of present level of precisions may be reduced on the order of 15 to 30 percent. The net effect of such tools to the users will be important, but rather transparent. Their use may be evident only by a footnote at the bottom of customary tables indicating their nontraditional derivation. While these techniques are helpful in the state and regional forest survey efforts, they also are applicable to State and county lands in phase II inventory efforts of the DNR and county forestry departments.

2. Forest covertype area estimation

The above estimation approaches are being considered in conjunction with large and small scale aerial photo coverage as a means of omitting ground checks for forest land classification and for improving the precision of estimates of forest covertype area. It is clear from past forest surveys in Minnesota that volume and other quantities per acre for particular cover types, say, jack pine pole-sized stands, has remained relatively constant over several decades. The acres or amount of acreage in such classes, however, has changed--stands have moved to larger size classes or have been converted into other species classes. Much of survey, then, is geared to identifying the dynamics of the acres involved among the covertypes. It is anticipated that large and small scale aerial photo coverage together with empirical Bayes concepts can lead to improved inventory speed, precision, and reduced sampling costs (see Figure 1). Current emphasis is on the development of a forest sampling simulator for such designs. This work is being facilitated by several staff at the College, including the Remote Sensing Laboratory.

3. Growth and yield projection model development

The availability of the forest survey data base allows numerous analyses of alternative managment practices. To aid in this, the North Central Station has developed the FREP program STEMS growth projection model. College staff have also developed an operationally oriented projection model called MFPS, based on STEMS, that is geared to the analysis of silvicultural and economic alternatives from this data base (see Ek *et al.* 1980). The MFPS program plus a condensed survey data file allows analysis of many utilization and supply questions for the future in a rapid manner.

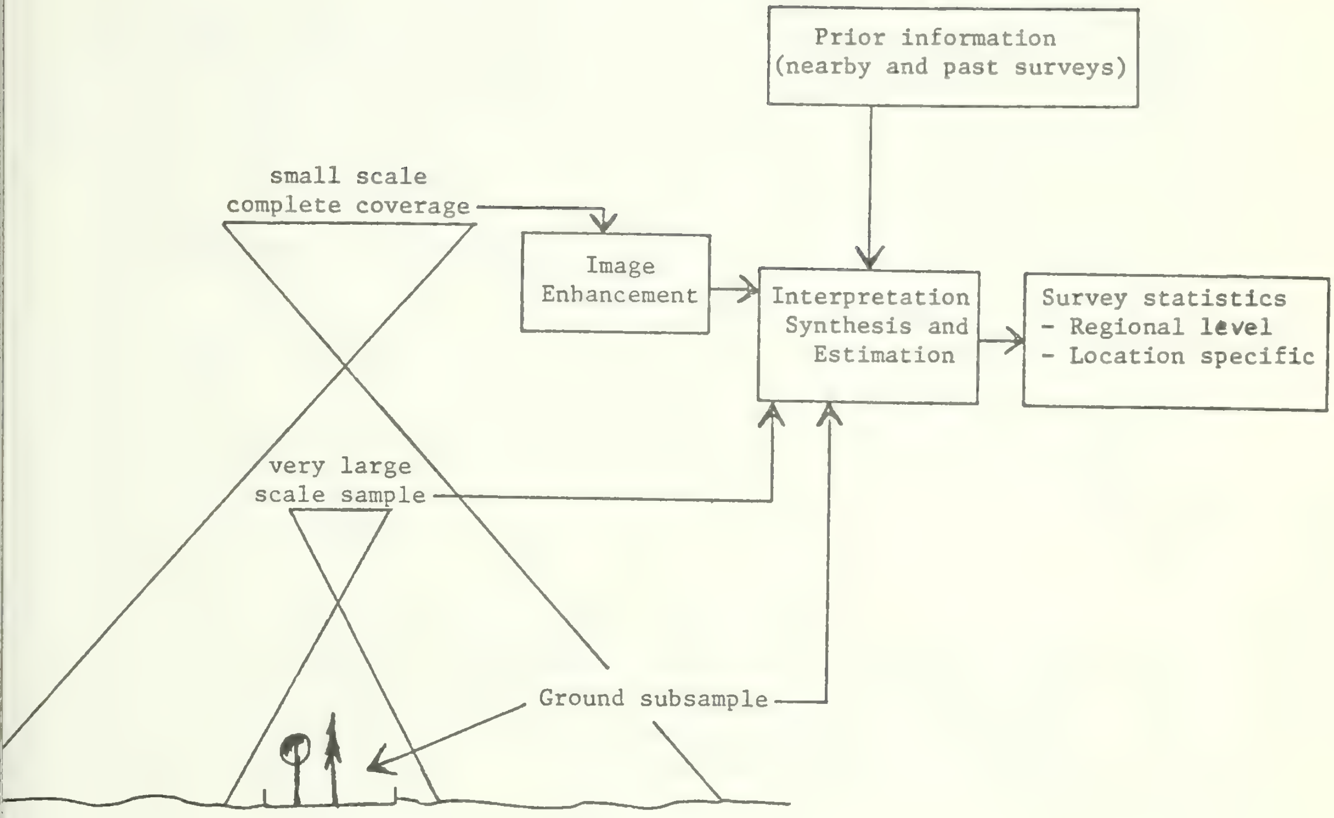
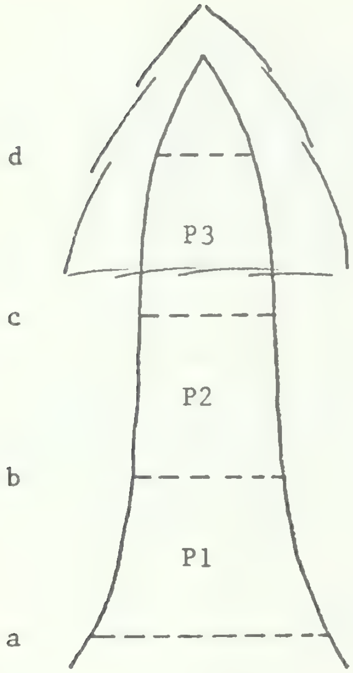


Figure 1.--A potential sampling design for forest surveys.

4. Implication of tree utilization changes via volume and taper models

The availability of the data base allows reprocessing of the inventory for entire regions or subsets with multi-product utilization conversions that allow addressing supply questions for particular products or combinations of products which trees might be broken into. Recent work in the College has led to taper curves for developing such multi-product volume tables. The illustration below (Figure 2) indicates how the product volume of a tree section can be derived.



$$P2 = \pi \int_b^c Y^2 \, dX$$

where Y = diameter from taper model
X = distance from tree tip

Figure 2.--The volume in the section from b to c can be derived by taper equation integration and sorted to product categories (e.g., P2) based on the section top diameter. Other product volumes can be derived in a similar manner.

Use of Forest Survey Inventory in Economic Analysis

Inventory data are currently being used extensively in research projects emphasizing timber management aspects of the forest resource. This reflects on the one hand the prevalence of traditional inventory data, e.g., volumes, heights and basal area of trees, but it also emphasizes the importance of timber management for other forest uses. Regulation of the severely unbalanced aspen inventories in the State through increased cutting activity, for example, is necessary to improve deer and grouse habitat and will also provide better access for recreation and other forest management activities.

This section describes five ways in which Forest Survey data are being used in analyzing and modeling forest resource decisions. They are:

(1) Physical timber supply estimation
(2) Economic timber supply (transportation and access analysis)
(3) Timber harvest scheduling and allowable cut calculations
(4) Analysis of timber investment opportunites
(5) Regional impact analysis

It is not possible to describe in detail each of these applications. We will, however, show examples of the various ways in which inventory data support such analyses.

1. Physical timber supply

Physical timber supply data were generated in the form of summaries by regions, owners, covertypes, and site index and age class combinations by a summary program to convert raw data into a form useful for economic analysis. One of the features of our summary program is the generation of data not recorded in the inventory. Examples of the latter are total and harvestable biomass, and various wood gross energy equivcalents (see Table 1).

2. Economic timber supply (transportation and access analysis)

Physical timber supply data have limited usefulness for economic analyses of timber production. Many stands are not accessible or are far from markets. Thus, the cost of making stands accessible and transportation costs must be analyzed. Figures 3-6 illustrate results of an analysis of transportation costs and timber supplies by distance class for State-owned aspen stands over 50 years old with Bemidji as the market center.

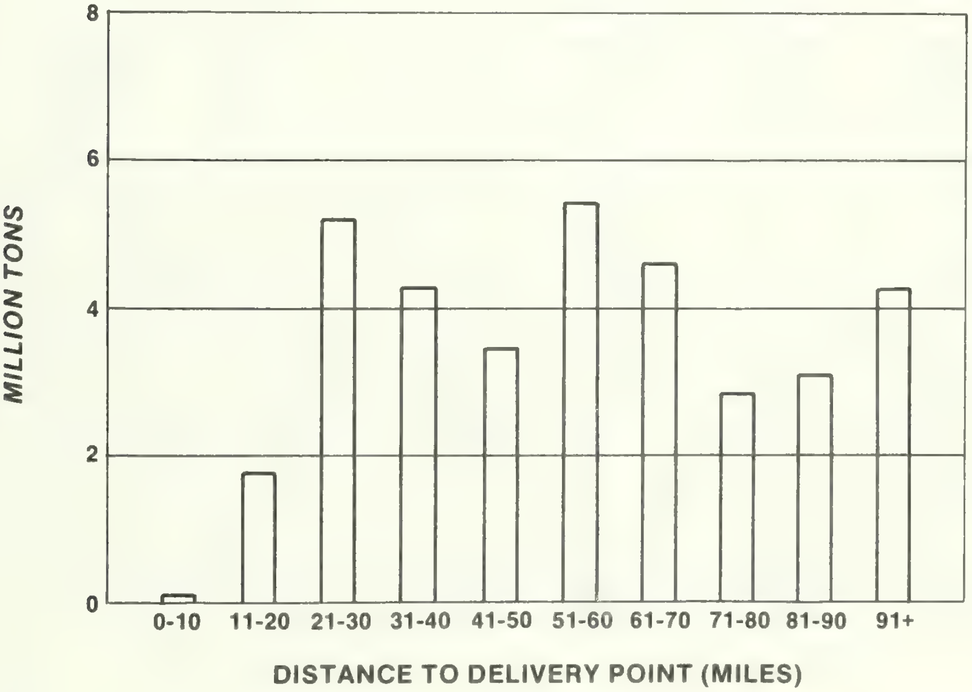


Figure 3.--Volume by weight of publicly-owned, mature hardwoods in the aspen forest type in Minnesota's Northern Pine Unit in relation to its distance from Bemidji.

Table 1.--Total biomass in tons
for all ownerships, Minnesota,
Northern Pine Unit

AGECLASS	5	15	25	35	45	55	65	75	85	95	>105	TOTAL
OAK-HICKORY												
S <40	2386	0	0	0	0	0	40904	0	0	0	0	43291
I 41-50	9925	0	0	0	94855	77862	0	0	49234	0	0	231878
T 51-60	0	0	0	34280	149626	184926	59042	0	0	0	0	427875
E >60	0	0	0	0	291018	144246	0	0	0	0	0	435265
TOTAL	12312	0	0	34280	535500	407036	99947	0	49234	0	0	1138312
LOWLD HDWDS												
S <40	11634	53183	12873	34122	0	56640	0	40514	136496	0	237293	582758
I 41-50	0	0	78787	32340	0	149830	103312	80753	0	0	0	445023
T 51-60	22291	27830	0	43605	115155	149370	114203	426342	122792	0	0	1021591
E >60	0	0	0	46834	245011	146333	0	13197	0	0	121274	572649
TOTAL	33925	81014	91660	156901	360166	502175	217515	560807	259288	0	358567	2622022
NORTH HDWDS												
S <40	0	23787	0	0	0	0	0	0	0	0	0	23787
I 41-50	0	0	46926	0	0	197736	92219	49936	94531	64825	56841	603016
T 51-60	0	44639	9563	35084	272002	449934	216107	434280	123287	0	72739	1657638
E >60	1749	0	0	137025	319061	653365	198729	0	0	255816	0	1565746
TOTAL	1749	68426	56489	172109	591063	1301036	507055	484217	217819	320641	129580	3850189
ASPEN												
S <40	6996	456	20769	12402	25594	0	121650	0	0	0	0	187869
I 41-50	80178	257118	63795	69270	112218	414346	157017	109485	62551	0	145800	1471780
T 51-60	117556	434674	121375	368810	274554	492229	180583	232674	119767	0	0	2342227
E >60	454829	495815	884488	4108068	5144981	3619886	1861737	46988	0	0	0	16616797
TOTAL	659560	1188066	1090429	4558552	5557349	4526462	2320988	389147	182319	0	145800	20618674
PAPER BIRCH												
S <40	0	31640	0	0	0	61024	0	0	126161	0	0	218826
I 41-50	39113	0	0	25792	21299	65188	18138	87618	0	0	45798	302949
T 51-60	0	20134	0	0	132659	104015	30205	0	0	0	0	287015
E >60	30786	0	113638	335315	708884	413784	292151	0	0	0	0	1894561
TOTAL	69900	51775	113638	361107	862843	644013	340495	87618	126161	0	45798	2703352
BALSAM POP.												
S <40	29098	5738	8070	0	0	26209	0	0	0	0	0	69117
I 41-50	7080	76119	101364	249035	5027	46467	38368	0	0	0	0	523463
T 51-60	70872	133257	77396	42336	182946	153017	10980	76710	0	0	0	747518
E >60	57761	128318	50797	155459	225741	545001	333844	0	0	0	0	1496923
TOTAL	164813	343434	237628	446831	413715	770696	383193	76710	0	0	0	2837022
OTHERS												
S <40	691847	605525	836448	967657	496742	693293	534135	673982	1271553	340682	1814110	8925978
I 41-50	73444	221286	492503	116460	433725	1021987	747102	399561	322058	136664	278697	4243491
T 51-60	74234	75096	224347	71884	744474	778707	240620	483424	0	138074	0	2830864
E >60	55350	49032	277263	258250	346266	609391	601408	0	0	0	0	2196962
TOTAL	894876	950940	1830563	1414253	2021209	3103379	2123267	1556968	1593611	615420	2092808	18197297
GRAND TOTAL	1837137	2683656	3420411	7144034	10341846	11254799	5992463	3155469	2428434	936062	2772556	51966870

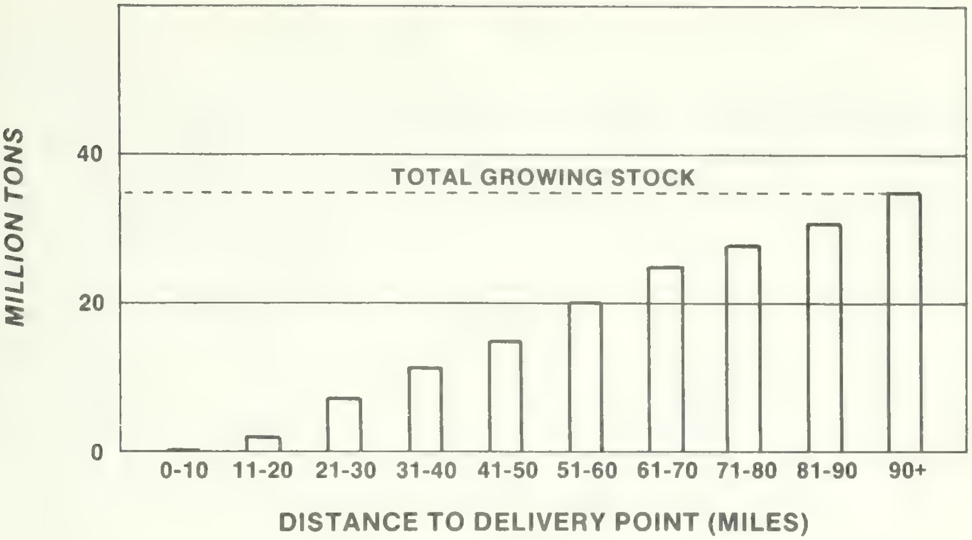


Figure 4.--Cumulative volume by weight of publicly-owned mature hardwoods in the aspen forest type in Minnesota's Northern Pine Unit in relation to its distance from Bemidji.

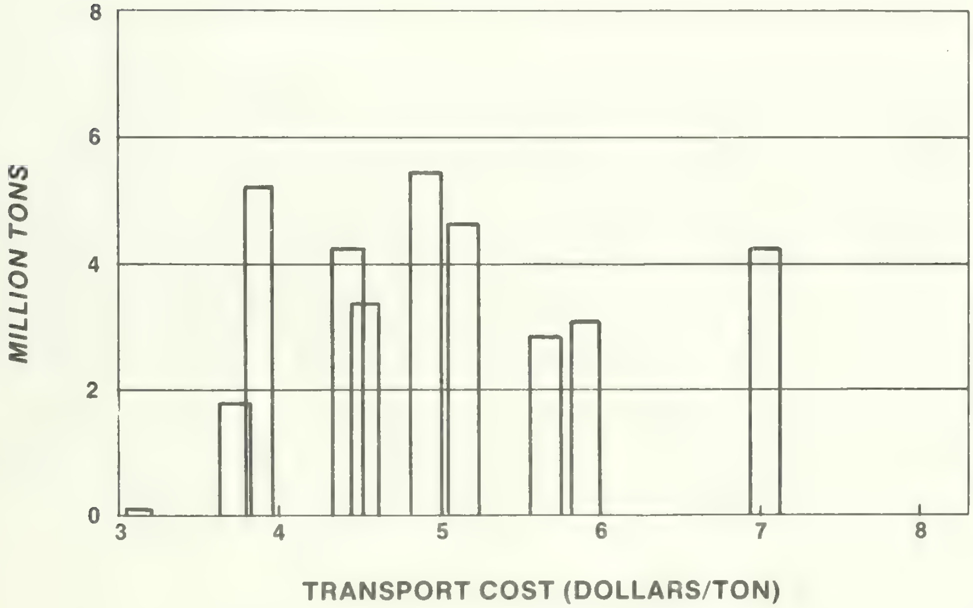


Figure 5.--Transport costs to Bemidji for volumes by weight of publicly-owned, mature hardwoods in the aspen forest type in Minnesota's Northern Pine Unit.

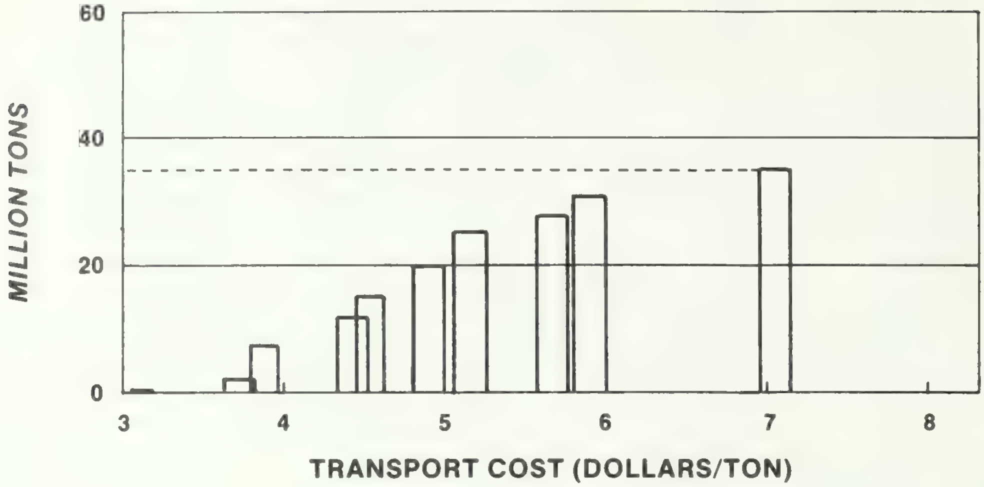


Figure 6.--Cumulative transport costs to Bemidji for volumes by weight of publicly-owned mature hardwoods in the aspen forest type in Minnesota's Northern Pine Unit.

3. Timber harvest scheduling and allowable cut calculations

The scheduling of timber cuts over time is important to achieve the goal of full regulation and to determine long-run sustainable cutting levels over time for specific covertypes and ownerships. Regulation can utilize many different procedures, each with its own implications for growth, growing-stock volume, and allowable cut. To examine implications of various regulation methods and cutting levels, a simulation model was developed to project timber inventories over time (Rose and Burk 1980).

Figures 7-10 present results of a simulation of the Tabular Check volume control procedure for State-owned aspen in survey unit 2 in terms of growing stock, allowable cut, and age class distributions.

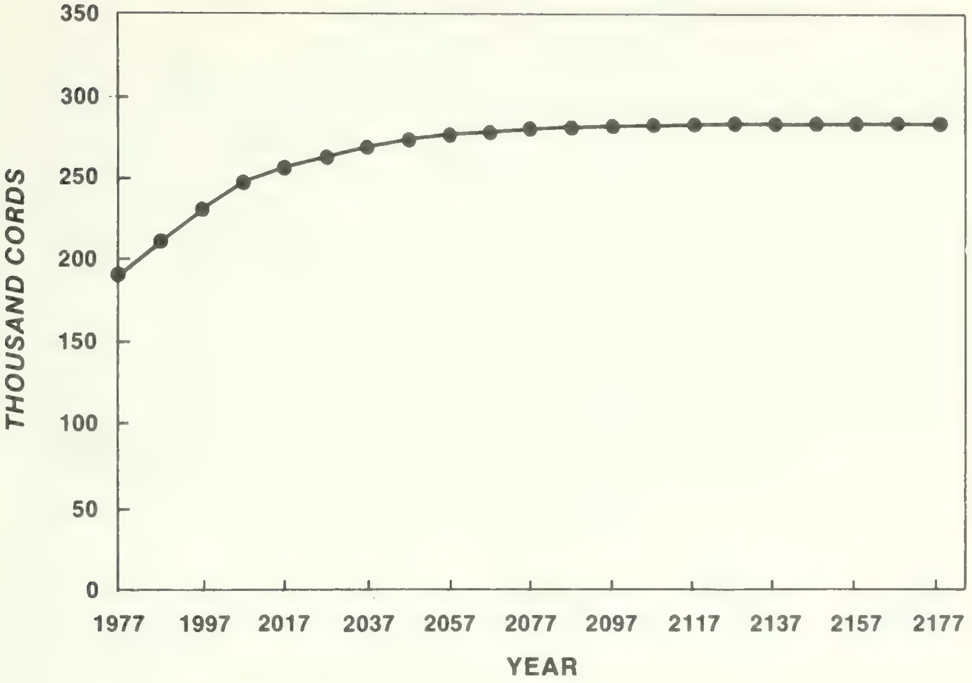


Figure 7.--Aspen allowable cut levels for State-owned lands under management in Minnesota's Northern Pine Unit.

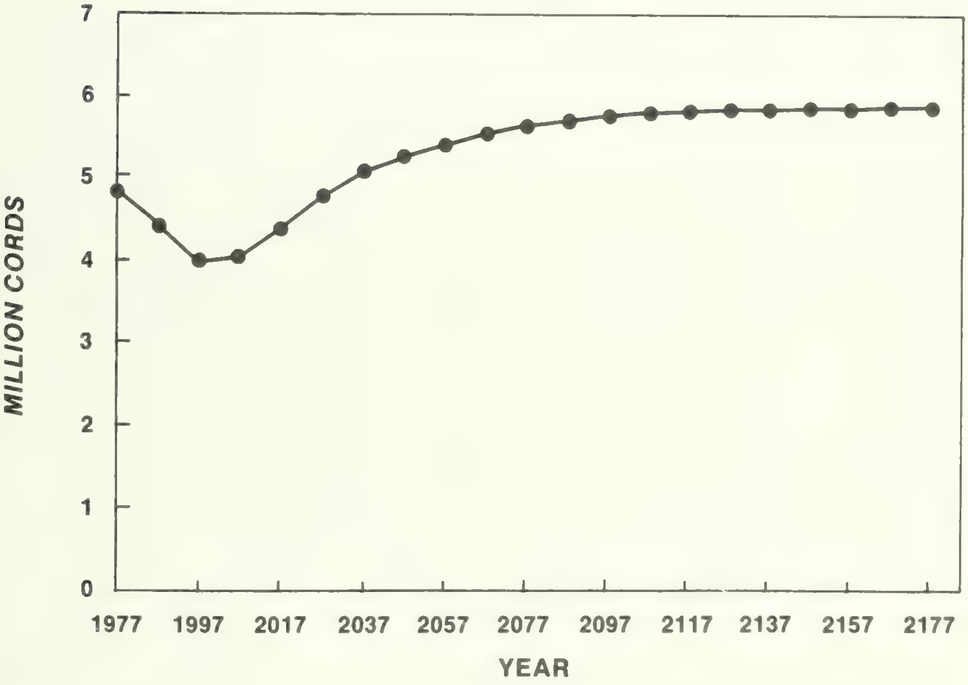


Figure 8.--Aspen growing-stock inventory levels on State-owned lands under management in Minnesota 's Northern Pine Unit, if allowable cut levels shown in Fig. 7 are maintained.

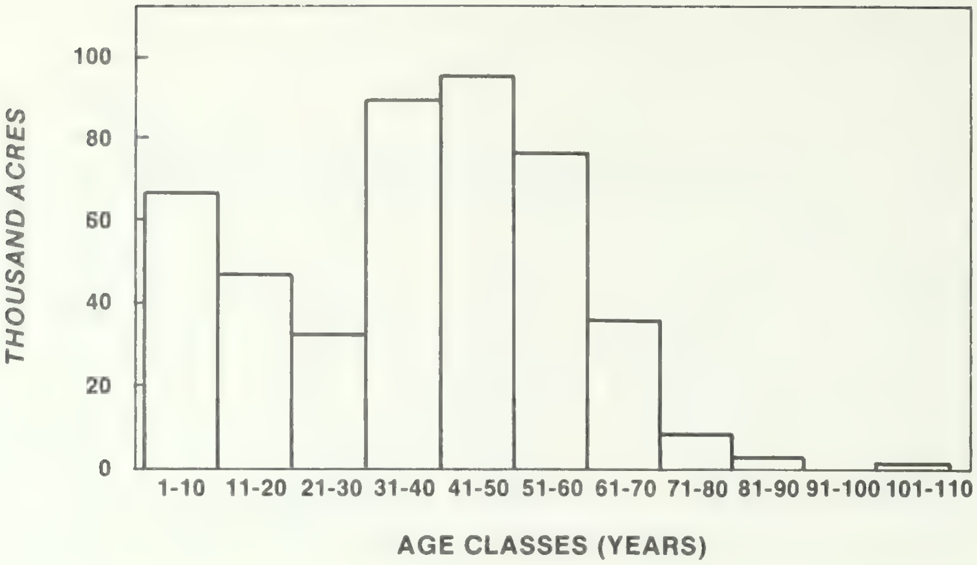


Figure 9.--Area of State-owned commercial forest land in the aspen forest type by age class in Minnesota's Northern Pine Unit in 1977.

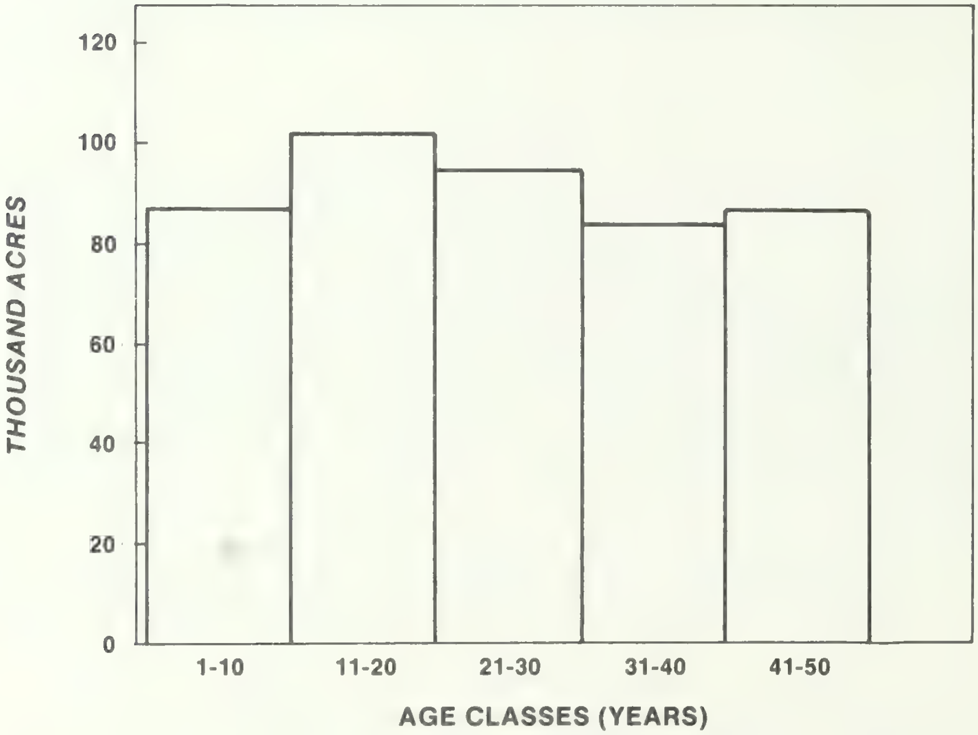


Figure 10.--Area of State-owned commercial forest land in the aspen forest type by age class in Minnesota's Northern Pine Unit in 2027, if allowable cut levels shown in Fig. 7 are maintained.

Other studies are underway which deal with scheduling of cuts by cutting priorities based on observations recorded for individual plots or stands. Sorting procedures used to establish cutting priorities are being compared with optimum cutting schedules generated by linear programming procedures. The latter can only be applied to aggregated stand data which cannot take into account individual stand characteristics important in cutting decisions.

Another project is analyzing procedures to set stand harvesting priorities for the aspen covertype which would achieve the highest degree of softwood production from the large softwood component of that covertype. Alternative harvest priorities already tested show substantially different softwood yields over time.

4. Analysis of timber investment opportunities

Specific covertypes, regions, and ownerships are being selected from the inventory data for analysis of potential economic returns of timber management. This research has concentrated on determining optimal economic rotations, potential for site conversion of off-site aspen and more intensive forms of management. The potential of wood as a source of energy in small power plants has also been analyzed (Rose and Olson 1979a, b).[1]

5. Regional impact analysis

Once timber inventories have been analyzed in terms of physical and economic supplies, and long-term sustainable yields have been determined, it is feasible to develop regional scenarios to utilize available timber resources. For example, based on projection of the aspen covertype of unit 1 under various timber management intensities, we developed several regional scenarios including new industries such as waferboard and small power plants.[2]

The potential regional impact of these new industries was analyzed via a regional input-output model developed by the Department of Agricultural Economics, University of Minnesota.

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[1] Aube, P. 1980. Cost analysis for a 25 megawatt wood-fueled power plant in Minnesota's inventory region 2. Unpublished M.S. thesis, College of Forestry, University of Minnesota.

[2] Erkkila, D. 1980. Forest management opportunities and associated regional impact for northeastern Minnesota. Unpublished M.S. thesis, College of Forestry, University of Minnesota.

Shortcomings and Opportunities

No one knows the shortcomings of the forest survey better than those intimately involved with it, i.e., those who process and analyze it. It is clear that data processing has become an important time-consuming element of the forest survey. We now have computer programs that process thousands of records in seconds; however, it frequently takes weeks and months to set up such runs and similar time subsequently to assure that they are, in fact, correct computations. This setup and check time is a function of the complexity of the data set and the sampling design and there are a number of trade-offs that must be made in developing the actual design for any area. As the survey has evolved, especially in the last few years, numerous observations for variables other than timber have been added to the survey. The survey design in terms of field plot and processing costs has become a major factor in consideration of redesign. Costs of several hundred dollars per plot are not uncommon.

With such problems it is instructive to note that forest survey is going through a period of change where more and more variables are being suggested for inclusion and designers are seriously considering whether one survey can handle the entire task. We may find that separate surveys for timber, water, wildlife and aesthetic resources might be more efficient. In terms of analyses, the availability of the data through the System 2000 data base package, contemporary computer facilities, and projection models like STEMS or MFPS plus analysis programs like those developed by North Central and College resource analysis staff, offer many opportunities. Techniques for analysis are evolving and will become more penetrating as repeated observations become available and various approaches and their veracity can be verified.

The selected applications of survey data described here emphasize the importance of the availability of these data at frequent intervals. Ten or fewer year periods between surveys are critical if the data are to be truly effective for decision making. Data should further be collected for specific purposes which have been identified before the final design and execution of a survey. Since resource management decisions are the endpoint of any data collection endeavor, an examination of typical management decisions in forest resource management should provide an insight into basic data needs. The nature of the current sampling design and resulting plot data limit the use of the data to decision models at the regional planning level and largely rules out their use for decision making at the operational or field level. The latter decisions will require the location specific kinds of data which are currently collected by National Forests and the State DNR in their phase II inventories. It is important that regional survey efforts move to encompass such objectives and that greater speed and efficiency be added to all of the various inventory efforts.

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HOW FOREST INDUSTRY USES INVENTORY INFORMATION

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Grand Rapids, Minnesota

My participation in this conference is as a representative from the forest industry responding to the question of how the forest inventory data is used by industry. I will attempt to do so from two perspectives. The first will be in a general way from the industry's viewpoint and in some more specific details from Blandin's experience.

The needs by industry for an accurate and current inventory of its raw material resource is obvious. No business, large or small, can logically plan its operation without an inventory. When we speak of the forest industry, we are concerned with the third largest industry in Minnesota having a physical plant value in 1977 in excess of 468 million dollars for the pulp, paper and paper board portion of the industry. In addition, there is a very significant investment in physical plants for the solid wood industry. The total industry provides jobs for approximately 54,000 people. Blandin's last paper machine, put on line in 1975, cost approximately 50 million dollars. The planned expansion of our waferboard plant will be approximately 37.5 million dollars. St. Regis has just announced a 200 million dollar expansion at Sartell, Minnesota. These are examples of major and costly expansions and typical of the costs being incurred by the industry. We must be assured that the forest resource is available to assure their success.

I see the uses and needs for the forest inventory by the Minnesota industry to be as follows:

1. Industry needs to have accurate and current information on the amount of raw material available by species.

   We need this basic data to make a proper assessment of the resource. It will be up to us to make our own assessment of this information. We must decide the availability of resource to our own operations. The resource must be available in the quantities needed and at a price that can be justified to make a profit on the manufacture of the end product.

   With the possible exception of some smaller sawmills and some of the particle board plants, most forest industries in Minnesota are specific in their species requirements. Changing technology over time may change the proportions of a given species mix; but generally speaking, substituting one species for another is very difficult to accomplish in a short period of time. For this reason, the industry needs to have the resource information presented by forest types and species.

2. We must know the location of the resource.

   Location is and will continue to be a very critical factor in the resource considerations by industry. A study by the

American Pulpwood Association in *1974 indicated that it takes an average of 5.16 gallons of fuel to produce a cord of pulpwood from the stump to the mill. Of this amount, 2.61 gallons or 51% was for transportation. The availability and cost of energy for transportation will play an ever increasingly important role in the location of manufacturing plants in relation to the forest resource.

3. We must know the volume and condition of the resource by ownership.

   With approximately 63% of the commercial forest land in Northern Minnesota in public ownership, it is very important to the industry that we know the resource base within each ownership and how it is being managed. With this knowledge, an assessment can be made of the management by the responsible public agencies. We can then reasonably respond to any problems this data might indicate. For instance, if the indicated annual allowable cut greatly exceeds the actual drain of the resource, it might point out a problem in sales and marketing by the public agency.

   The same is true of the private nonindustrial segments of the commercial forest land ownership. Unless we know what the basic forest resource data indicates on those lands, it is very difficult for either industry, or for that matter the public agencies, to respond to problems relating to the management of nonindustrial forest land.

4. We must have an accurate and current assessment of the total drain on the resource.

   Industry must have an accurate and current picture of the total drain on the forest resource including both commodity and noncommodity uses. We all realize that it is difficult to obtain some of this information, particularly the noncommodity type uses such as home fuel, nonmarketed lumber, etc.; but in order to get the total resource picture, it is essential that the volumes used be identified as accurately as is possible.

5. An accurate assessment of the forest condition is essential information.

   This refers to the fact that we not only need inventory information to tell us how many trees are growing but we need to know how well they are growing. Nationwide, our forest lands are producing at about 50% of their potential rate. With an ever-dwindling commercial forest land base, we must increase the rate of growth on the remaining acres. Most of you are aware of the **Forest Productivity Project ini-

*American Pulpwood Association - Fuel Survey - 1974 Data.
**Minnesota Forest Productivity Report - 1979.

tiated by the Forest Industries Council to forestall a wood shortage that could occur in this nation by the year 2020 if measures are not taken to increase the productivity of our forests. The Minnesota study relating to this program indicates that by using the most apparent good forest management measures on the acres identified in the 1977 Minnesota Inventory as needing treatment, we could treat 4.5 million acres of commercial forestland for a resulting annual incremental yield of 213.8 million cubic feet of softwood and 58.7 million cubic feet of hardwood. The total cost of applying these management measures would be 535 million dollars.

This volume is four times the present consumption of softwood and is 70% above the current use of hardwood. By beginning such a program now, the incremental increase would begin coming on stream at about the time required to avert any potential shortage of wood in Minnesota.

6. We need an assessment by responsible public agencies of the implications of the forest inventory.

Although it was mentioned that industry must apply its own criteria to the basic inventory information, it is also essential that the responsible public agencies explain the implications resulting from the inventory information. For instance, the annual allowable cut information that has been discussed is from all ownerships and all types without regard to availability. This information can be very misleading unless the factors affecting availability are carefully analyzed and the material is presented in such a way as to recognize deductions to the total annual allowable harvest information. The confidence level of annual allowable information could be greatly enhanced by identifying the computations used to determine it. Factors such as rotation age, volumes per acre, growth rates and other critical criteria should be identified so that those using the information will have a basis of comparison with their own criteria.

7. We need to continually update and renew the forest inventory.

The last point I would like to make on the needs of a forest inventory by the industry relates to the timing. Fifteen years between inventories is, in my estimation, too long. Admittedly, with computerized models we now have better tools with which to update the inventory information, but a physical inventory should be made every ten years or less to keep an accurate handle on the resource.

We also feel that some method should be found to shorten the length of time between the completion of the fieldwork and the publication of the resource data.

Good current resource inventory information is absolutely essential when the industry is confronted by the political implications of forest resource management. The 1962 inventory

> data was completely ineffectual in proving the point that the industry tried to make in the BWCA controversy, that the softwood species were not available outside that area being locked up in wilderness. The 1977 inventory has proven the point but too late to be effective except in an intensified softwood management posture.
>
> The industry and the public can ill afford the political decisions based on old or unreliable data or misinterpretations of data which significantly affect the role of our forest resources and their place in the economy.

In order to respond to the specific uses of forest inventory information, I would like to give a brief background report on the formation and expansion of the Blandin operation.

Blandin Paper Company had its beginning with the Itasca Paper Company as a newsprint producer in 1901. The first mill produced about 25 tons of paper a day and cost approximately $230,000.00 to construct.

In 1923 a second newsprint machine was added bringing total production to 75 tons per day.

During the early 1930's it was clear that the large modern Canadian newsprint mills were going to make the Blandin mill obsolete, so the company installed a new machine capable of producing 100 tons of paper per day. In 1935 the mill began switching some of their production to groundwood specialty papers.

In 1946 newsprint production was eliminated entirely, and in 1955 a trailing blade coater was installed giving birth to the coated publication paper our mill now produces.

The next large expansion of the paper mill was completed in 1963 increasing production to 131,000 tons per year and providing jobs for 640 people.

By 1969, through modifications and rebuilds to existing equipment, production had increased to 188,000 tons and employment had reached 844 people.

I believe that it is true that to this point in the company's growth pattern, the major considerations for expanded operations were available markets and capital formation. The 1962 forest inventory indicated excess volumes of all species required.

In the early 1970's it became evident that market conditions would support another expansion of paper production. It was also known from the examination and analysis of resource inventory information that a large surplus of maturing aspen existed and that the harvest of this aspen resource would "free up" additional softwoods which could be used for a paper mill expansion.

The decision was made in 1970 to construct a building board plant to utilize the aspen resource. In 1972 this first waferboard plant in the country was completed at a cost of about 15 million dollars. This was followed by the largest expansion ever undertaken by the paper mill. Number 5 machine was put on stream in 1975 at a cost of approximately 50 million dollars. This brought our total production at the paper mill to over 308,000 tons per year with more than 1,100 people employed.

Indications of a greatly expanded market for building board led to the decision to expand the present manufacturing plant, and Blandin Wood Products Company is now embarked on a 37.5 million dollar expansion project with completion scheduled for mid 1981. This expansion will eventually triple the wood resource required at that facility.

We have reached the time in the growth of the forest industry in Minnesota when the available resource has become a very critical consideration when planning for new or expanded operations. If the demand for wood exceeds the supply, then only those industries capable of competing for the existing supply will survive.

New technology has allowed for some change in the species mix in the production of our paper. Blandin has gone from being a mill using primarily spruce groundwood to a point in time when we are currently using only 22% spruce, 23% balsam and the balance of 55% hardwood, primarily aspen. We also feel that through research and development, we will be able to utilize many of the hardwoods in addition to the aspen in our wafer board plant.

Present wood usage at both mills is 188,000 cords - 17% spruce, 18% balsam and 65% hardwoods. With the additional 140,000 cords of hardwood to be used eventually at Blandin Wood Products Company, our total corporate use of wood will be 79% hardwood and 21% softwood with the softwood component split fairly equally between spruce and balsam.

If we consider the growing-stock volume of the softwood and hardwood species that we will be using in our mills in the Northern Aspen - Birch Unit I and the Northern Pine Unit II, which are our mills' major wood sources, we find about a 75% hardwood - 25% softwood ratio. This indicates to our management that our usage of species is consistent with the resource our forest presently is growing.

From our examination of the resource data, we are convinced that the resource base is adequate for Blandin's present expansion and that we will be able to successfully compete for that resource. Our use of the resource inventory data is now directed toward identifying the logistical advantage for our mills' procurement program.

In summary, the forest industry is continually in need of the best and most current resource information available. Our future plans and programs are greatly influenced by the results of the forest inventory process.

We depend upon the public agencies and those in the academic field to analyze and distribute the results of the inventory in a clear, concise and unbiased fashion to all segments of society. Our use of the forest inventory information may be primarily directed toward utilization while

Others may be more interested in some other use aspect of the forest. In discussion of these sometimes conflicting uses of the forest, we should be able to find common ground from which to begin discussion in the forest resource information data.

Only by the continual updating and renewal of the Forest Resource Information can measurement be made of past management policies and practices and progress made toward improving them.

HOW ENVIRONMENTAL GROUPS USE INVENTORY INFORMATION

Wesley Libbey
Izaak Walton League
Grand Rapids, Minnesota

The primary use of inventory information is in analyzing resource problems and reaching conclusions which permit taking positions that are in the long term public interest. The better the data, the more likely it is that decisions based on the data will be useful and productive.

Forest inventory data will be one of the decisive factors in reaching a position on those forest related programs of the Congress, State Legislatures, public agencies or private enterprise dealing with land use or forestry practices and management.

Taking stock is the very first step in operating a business. It is fundamental to know what you have before you can make a plan of operation. A good inventory should be the beginning cornerstone of a good forestry program. It is my experience that we lack a good forest inventory. I hear public foresters say we have an adequate supply of trees and I hear industry foresters say they can't find them. An adequate forest inventory should be both comprehensive enough and detailed enough that it can supply answers to everyone's questions. I don't like being placed in the middle, having to make a decision about who is correct. Industry is entitled to know what wood supplies are available to enable them to produce the items we all need as consumers. And the wood-growing forester has the right to know the condition of his growing stock. Environmentalists should be able to feel that a position they take is based on a sound inventory. An inventory is a statement of fact--it should not be subject to question or various interpretations.

It seems to me that infrequent and inadequate inventories have been an outgrowth of a basic problem in forestry--lack of adequate funding and manpower. State legislatures and the Congress have historically regarded forests as a source of income, rather than as a resource which requires investment to produce a much greater return. This has resulted in concern about shortages of timber, which in turn, gives rise to many land-use controversies. Foresters know how to greatly increase forest growth given the funds and manpower required. If forestry programs had been adequately funded over the past fifty years, we would have timber running out of our ears and would not be having land-use conflicts about wilderness, parks, recreation, etc.. And yet today, we are still trying to accomplish the very first basic step--an adequate, acceptable inventory.

Investment in production of natural resources is a basic way to control inflation. An abundant timber supply would reduce the cost of housing. Most long-range planning in our nation extends out about four years -- from one presidential election to the next. By contrast, investment in forests needs to cover fifty to one hundred years. An adequate investment in forest management over the years will help to reduce inflation, improve the balance of payments and return a profit to finance future good management of the forest resource.

I would also like to point out the need for information by environmental groups, not only from an adequate forest inventory, but also for the need to update this information periodically. Up to now we have had to rely on inventory data released about 1962. Many environmental decisions have been required during this long period of increasingly out-of-date information. Environmental decisions require many different types of data. An inventory should be detailed enough to provide the variety of answers environmental groups need. They also need to have inventory data interpreted and analyzed. And they would find very useful, projections based on present data that could be made available between inventories. Inventory data from various land ownerships should be assembled on a statewide basis and also evaluated on a statewide basis. All these are necessary to environmental groups in reaching sound decisions.

In Summary

1. Environmental groups repeatedly make decisions based on forest inventory data.

2. An inventory is a basic first requirement.

3. The inventory should be comprehensive and detailed enough to answer all questions.

4. Inventories should be periodic and updated frequently.

5. Adequate funding of forest inventory and management is in the long term public interest.

6. Environmental groups need inventory evaluation, both detailed and statewide, and projections between inventories.

HOW THE NATIONAL FORESTS USE INVENTORY INFORMATION

James A. Mohler
Timber Staff Officer
Chippewa National Forest
Cass Lake, Minnesota

Most organizations have many sources of information with which to work. The National Forests in Minnesota have long depended upon the Forest Survey effort as one of these sources.

At present, there are two very specific pieces of data that come to us solely from the survey. One of these is growth, the other total volume. Both of these items come from a series of permanent plots installed on the Forests which are remeasured each time a survey is conducted.

While both National Forests in Minnesota are operating under area control and, primarily, even-age management, growth data is important as a sounding board against which cut volume can be compared to insure we are not cutting more than we are growing.

Growth data is also a key ingredient in many automated models being used today to simulate the long range business of forest management.

Obviously, the better the growth data, the better and more acurate the projections will be.

Total volume is a figure that probably generates more interest outside the National Forests than internally. Forest industry particularly needs to know what the total available "woodpile" is. We regularly use Forest Survey total volume figures in response to external inquiries.

The expansion in the wood-using industry in northern Minnesota bears witness to the magnitude of the decisions that may be made on the weight of such data.

Total volume data is also used as a check on progress made towards certain management objectives. For example, if management has the objective of increasing the jack pine component on the forest; one has but to study the volume figures from one survey report to the next to see how things are coming along. If it hasn't increased, something might be wrong.

As we do our long range planning, other types of Forest Survey data are also useful to us. Information regarding trends and utilization is very helpful in making long range demand projections. One of the products the National Forests produce is raw material for the wood-using industry. By knowing what the trend is in commercial forest land over all ownerships; we can better gauge the importance of our role as a stabilizing influence in local situations.

Trends in certain timber types or age classes are indicators of what might be reasons for trends in other resources. Potential problems can be identified and corrective action taken if related trends are studied. As an example, if a high priority objective is increasing the ruffed grouse population, and you see a downward trend in the aspen type--watch out!

Utilization data is of key importance to a raw material producer. In the long range business of forest management, an answer to the question "how much of what shall we produce?" is difficult to come by, and I might add, the source of much discussion among foresters and forest managers. Forest Survey data regarding utilization helps us formulate alternative answers to that question by providing good information on what's being used and where it's being used.

To more fully understand the use of inventory data by the National Forests, it might be helpful to know something of our internal needs and the methods we use to satisfy those needs. Land classification provides an illustration. The decision to classify forest land as commercial forest land, or something else (productive reserved for example) is to decide whether or not wood products from it are available as a commodity.

The Forest Survey before you tells us that there are nearly 14 million acres of commercial forest land in the State. The Chippewa National Forest contains 562,000 of those acres. In using that figure on the Chippewa, it must be broken down into our own sub categories. We recognize 13 sub categories of commercial forest land. Each one carries with it certain policies and coordination rquirements that directly affect the management activities on that piece of land, and the available volume that can be planned to come from it. The method we use to get this type of site-specific data is called compartment examination. One of the outputs of this examination is a stand-by-stand identification of land use class.

Another example can be found in the figures on area by timber type. There are 5.3 million acres of aspen type in the State. The National Forests contain 598 thousand acres of the aspen type. The Chippewa National Forest contains 207,000 of those acres--someplace! In order to plan ahead for timber sales, we must know exactly where those acres are.

Again, compartment examination provides the answer on a stand-by-stand basis.

The point being made is evident. The more intensely an organization manages its land, the more specificity is required in the data. On the National Forests, Forest Survey data provides the foundation from which land management planning begins. Our internal systems refine that data to the level of site-specific projects such as timber sales.

How many times did you hear the word PLANNING during this conference?

Planning has become one of the key words in the natural resource manager's vocabulary. Managers of the National Forests are acutely aware of the value of sound data upon which sound plans must be based. In all likelihood, we will continue to depend on the Forest Survey as one of our sources of this data.

HOW FOREST RESOURCE CONSULTANTS USE INVENTORY INFORMATION

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George Banzhaf & Company
Forest Resource Consultants
Milwaukee, Wisconsin

Introduction

I am certain that the Minnesota Forest Resource Inventory Conference will help to promote a better understanding of the importance of inventory information, the present usage for these data, as well as the future needs of various user groups. I am hopeful that conferences of this sort will be repeated in other states when their new survey information becomes available.

Inventory systems and information are the foundation for sound and efficient management decisions regarding any commodity, whether it be nuts and bolts in a hardware store or trees in a forest. You must know what you have before you can determine what should be done with what you have.

As a forest resource consulting firm, George Banzhaf & Company, serves those involved in the use of forest resources by providing an independent and, hopefully objective, point of view in the management of those resources. Although we have worked on occasion with the small landowner sector, our primary client base is the organization involved in the management of large tracts of timberland. In the private sector this includes, primarily, the forest industry. In the public sector, state and federal land management agencies, as well as regional and state planning commissions, are the prime users of our services.

Our involvement with forest survey information as published by the USDA Forest Service ranges from the installation of field inventory plots to the analysis of data on a unit or regional basis.

Resource Analyses

The types of analyses we perform with inventory data can be delineated into two basic categories:

1. State or regional supply studies for land use planning and development.

2. Feasibility studies involving the location of a new forest products converting plant or the expansion of an existing facility.

The regional or state planning agency normally wants to obtain a better understanding of the economic development potential of the resources within the region. This client also is concerned with providing a balance of economic development with the allocation of resources to meet the needs and desires of the citizenry. This would include forest products production, recreation opportunities, and wilderness preservation.

The client from the industrial sector is primarily concerned with determining whether there is sufficient wood supply to justify expansion or location of a new converting facility. This is, indeed, a critical factor. No matter what forest products facility is planned, it is no better than its wood supply. Because investments range from $500,000 for some sawmills to as much as $1,000,000,000 for a large paper mill, forest survey or inventory data had better be accurate as well as understandable.

Whether it be for a regional land use planning study or a mill location study, there is certain information which we find of particular value in gaining an understanding of forest resources and their availability for development. They are the following:

Data or Inventory Component	Study Use or Value
1. Area by land classification.	This component is helpful in determining land use patterns and changes.
2. Area by site.	This gives an indication of the productive capacity of a region.
3. Area and volume by ownership classification	This component is helpful in determining the availability of the forest resource as reflected by assumptions on differing landowner management objectives.
4. Area and volume by species and forest type	This is valuable in determining whether or not

Data or Inventory Component	Study Use or Value
	specific wood supply needs can be met both in terms of volume as well as general level of concentration.
5. Volume by product and diameter classification	It is important to be able to view the timber resource in terms of the volume of the material that can be economically utilized by the client you are serving.
6. Volume by stand-age class	This information is important in determining whether or not the age class distribution is out of balance. In those cases where excessive volume is in the older age classes, initial harvesting activities over and above annual growth would be required
7. Growth and removal or drain data	This information will be of assistance in determining the sustained yield capacity of the region as well as indicating that portion of the sustained yield capacity which is currently being used.

Data Limitations

In obtaining a true understanding of the value of this information it is equally important to understand the limitations of survey data.

Forest Survey data are generated through a light statistical sample. The sampling procedures result in excellent statistical reliability when the data are used for a State as a whole or for a specific survey region (for example, Aspen -- Birch unit of Northeast Minnesota). Unfortunately, this information is misused when localization to the County level is attempted. County information is available and, in terms of overall acreage and volume, is relatively reliable. Specific volume data by species, however, are simply not statistically meaningful. These data should only be used as general indicators and not as definitive answers.

In addition, it is important to understand that the Forest Survey deals, primarily, with biological or physical availability. It does not deal with economic availability. Although some indication of economic availability can be gained through an understanding of volume per acre, the matter of physical access is an important component not included in survey information. Forest Survey information should be considered as an excellent regional planning tool -- no more!

Future Survey Needs for the Consulting Firm

It is my opinion that increased accessibility to the raw field data or plot data would be extremely helpful to consulting firms. This would enable the private sector to have the flexibility to compile their own tables for their own purposes. I am fully aware that any data or information so created could not have the approval or certification as to its accuracy by the Experiment Station. Nevertheless, expertise in this field is no longer limited to the Experiment Station or the University level. It is my understanding that there is a data retrieval system currently being developed which should be available in the near future.

With increasing pressure for up-to-date land use and resource information, it is imperative that survey remeasurements keep on schedule and are supplemented through the use of projection models to generate up-to-date information.

Closing Comments

I have attempted to show how very necessary and useful forest inventory information is to the consultant. The system when maintained and not allowed to become out of date, can provide an excellent regional planning tool. This information is critical to the effective management of our forest resources.

* * *

HOW REGIONAL PLANNERS USE INVENTORY INFORMATION

Steve Krmpotich
Arrowhead Regional Development Commission
Duluth, Minnesota

Introduction

This discussion will focus on three general areas. First for the benefit of those who are not familiar with sub-state government organization in Minnesota, I will describe the Regional Development Commission structure in the state and provide a general history and background of the Arrowhead Regional Development Commission (ARDC). Second, I would like to describe involvement by the ARDC in Forestry Planning and Forestry Management relative to the use of inventory data and other research information developed by the North Central Forest Experiment Station (NCFES). Third, I would like to comment on future concerns with forest inventory information and NCFES research in general.

Minnesota Regional Development Commission History and the Arrowhead Regional Development Commission

The thirteen Regional Development Commissions that exist in Minnesota today were made possible through the Minnesota Regional Development Act of 1969. This legislation established the structure and role for Commissions. The broad purpose for Regional Commissions in Minnesota according to the 1969 Act is to "facilitate intergovernmental cooperation and to insure the orderly and harmonious coordination of state, federal, and local comprehensive planning and development programs for the solution of economic, social, physical, governmental problems of the state and its citizens." The legislation also provides authority for Regional Commissions to receive state and federal grants for regional purposes, to conduct broad planning on a multi-governmental and individual government basis, and to conduct comprehensive planning for the overall geographic area within their jurisdiction. In addition, Commissions are empowered to review the plans of local government units, to review long-term comprehensive plans of other independent agencies within the region if such plans are determined to have a regional or a multi-governmental effect, and to review all applications for state and federal aid programs.

The ARDC was one of the first organizations of this type formed in the State of Minnesota. Because the Arrowhead Region had been an Economic Development District of the U.S. Department of Commerce, Economic Development Administration since 1967, the administrative structure and regional focus of the Development District made it an easy task for the agency to adopt the expanded Regional Commission role allowed by state legislation.

Figure 1

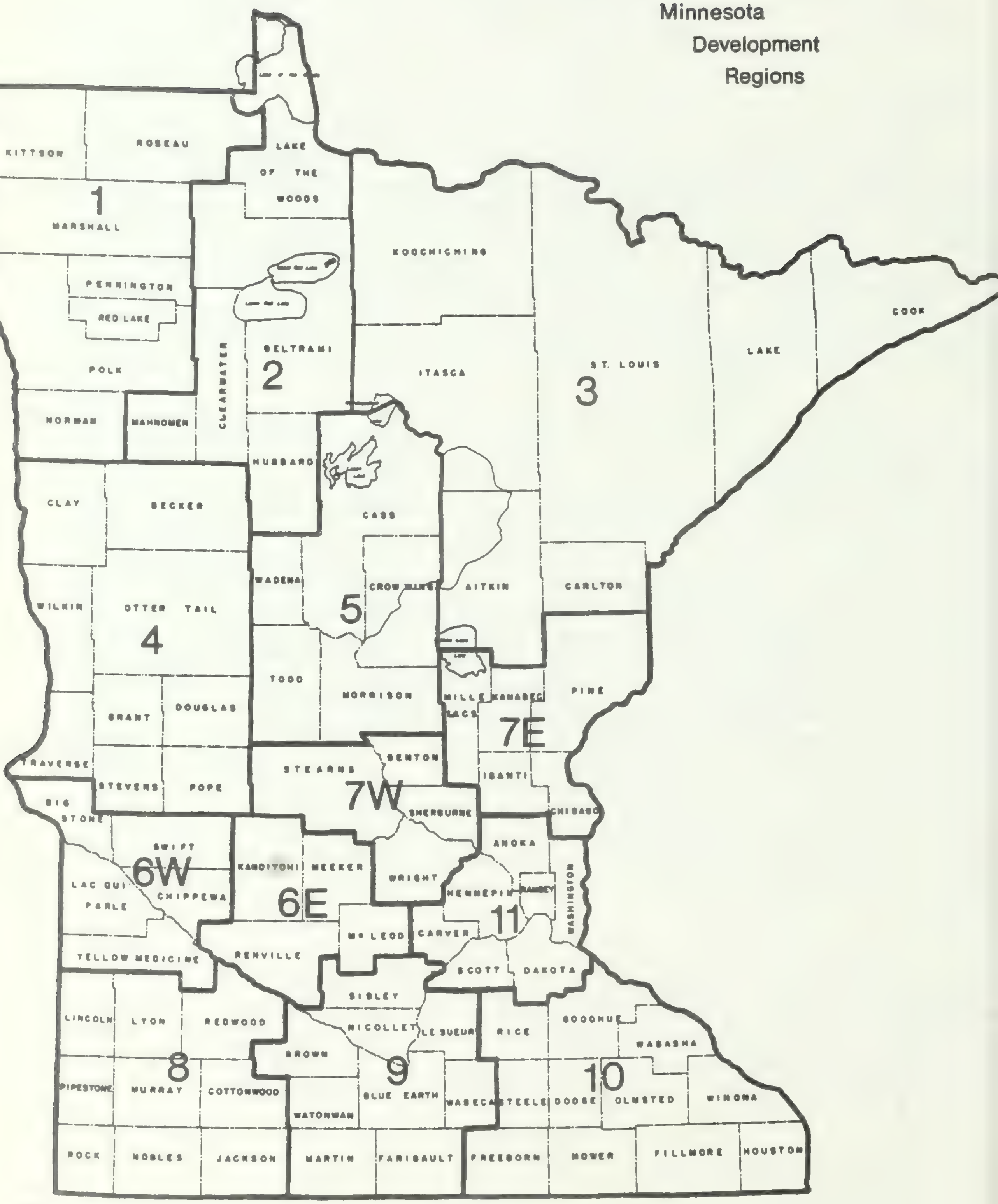
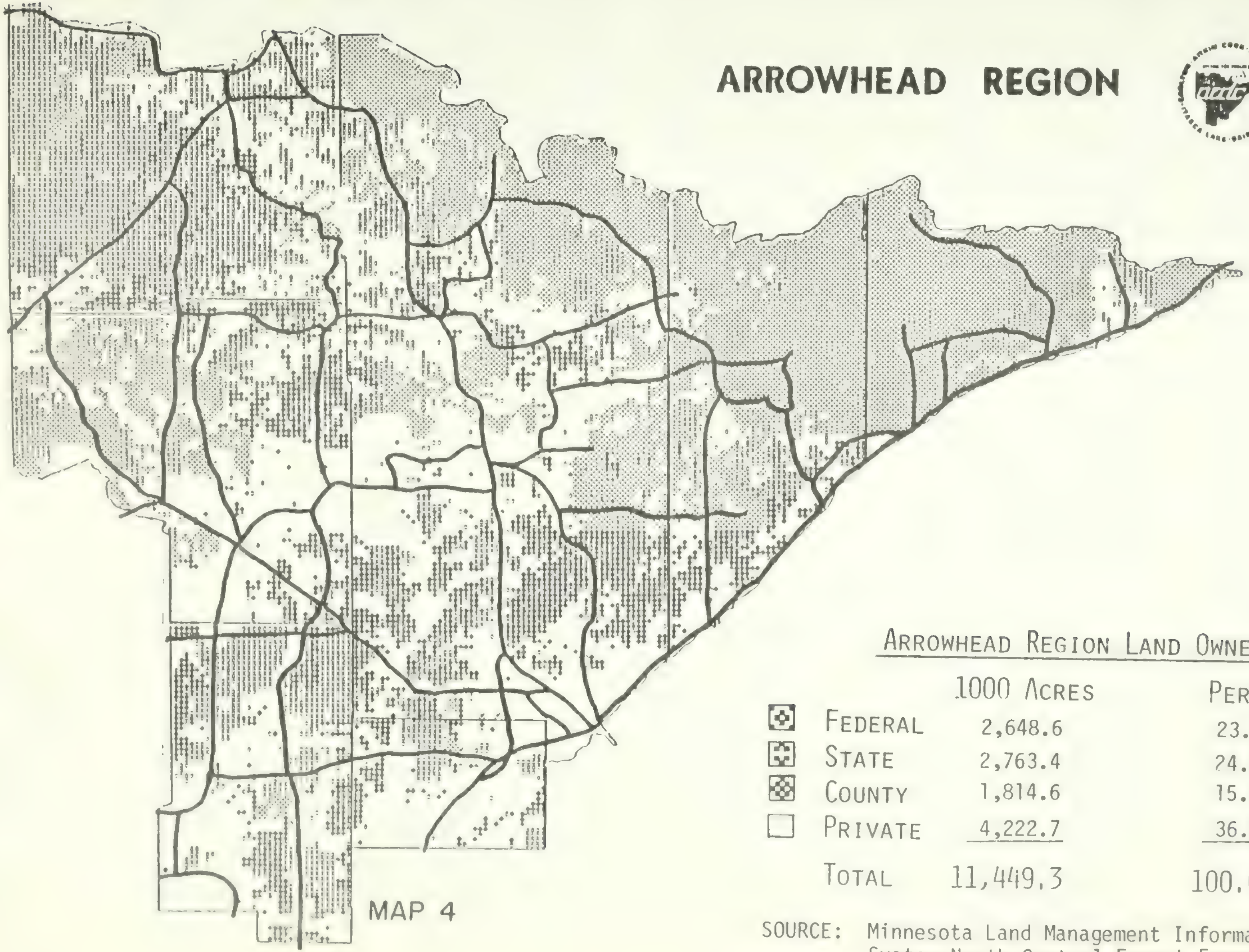

Minnesota
Development
Regions
KITTSON
ROSEAU
LAKE OF THE WOODS
1
MARSHALL
PENNINGTON
RED LAKE
POLK
NORMAN
MAHNOMEN
CLEARWATER
BELTRAMI
2
KOOCHICHING
ITASCA
ST. LOUIS
3
LAKE
COOK
HUBBARD
CASS
CLAY
BECKER
WADENA
CROW WING
AITKIN
CARLTON
WILKIN
OTTER TAIL
4
5
TODD
MORRISON
MILLE LACS
KANABEC
PINE
GRANT
DOUGLAS
7E
TRAVERSE
STEVENS
POPE
STEARNS
BENTON
ISANTI
7W
CHISAGO
BIG STONE
SWIFT
SHERBURNE
ANOKA
6W
KANDIYOHI
MEEKER
WRIGHT
HENNEPIN
RAMSEY
WASHINGTON
LAC QUI PARLE
CHIPPEWA
6E
11
McLEOD
CARVER
RENVILLE
YELLOW MEDICINE
SCOTT
DAKOTA
SIBLEY
LINCOLN
LYON
REDWOOD
NICOLLET
LE SUEUR
RICE
GOODHUE
WABASHA
BROWN
8
9
10
PIPESTONE
MURRAY
COTTONWOOD
BLUE EARTH
WASECA
STEELE
DODGE
OLMSTED
WINONA
WATONWAN
ROCK
NOBLES
JACKSON
MARTIN
FARIBAULT
FREEBORN
MOWER
FILLMORE
HOUSTON

Figure 2



ARROWHEAD REGION

MAP 4

ARROWHEAD REGION LAND OWNERSHIP

		1000 ACRES	PERCENT
⊡	FEDERAL	2,648.6	23.1
⊞	STATE	2,763.4	24.1
▩	COUNTY	1,814.6	15.9
☐	PRIVATE	4,222.7	36.9
	TOTAL	11,449.3	100.0%

SOURCE: Minnesota Land Management Information System North Central Forest Experiment State

A brief background of the Arrowhead Region will help provide reason to our agency's belief that a good forest inventory information base is necessary to good resource management in Minnesota. The Arrowhead Region encompasses seven counties in Northeastern Minnesota. In area, the region includes almost 20,000 square miles which is roughly one quarter of the state's total land area. The region is 80 per cent forested and contains slightly more than half of Minnesota's commercial forest land according to the 1977 forest survey. The amount of human resources in the Arrowhead Region contrast with its abundant natural resources; in 1970 the population was 337,000 or about 8.5 per cent of the total Minnesota population at that time.

The organizational structure of the ARDC includes a Commission of 53 members, a Board of Directors of 13 members and a number of Advisory Committees. The Commission is the policy making body of the organization and currently meets four times a year. The Board of Directors meets monthly and is charged with managing the affairs and the policies of the Commission. The agency has 12 functioning Advisory Committees. These Committees have their own operating by-laws, are supported by ARDC staff, and play an important role in developing ARDC policy. Policy statements or policy positions that are developed by Advisory Committees are forwarded to the Directors and Commission for approval prior to transmittal to governmental agencies and funding sources.

ARDC and Forestry

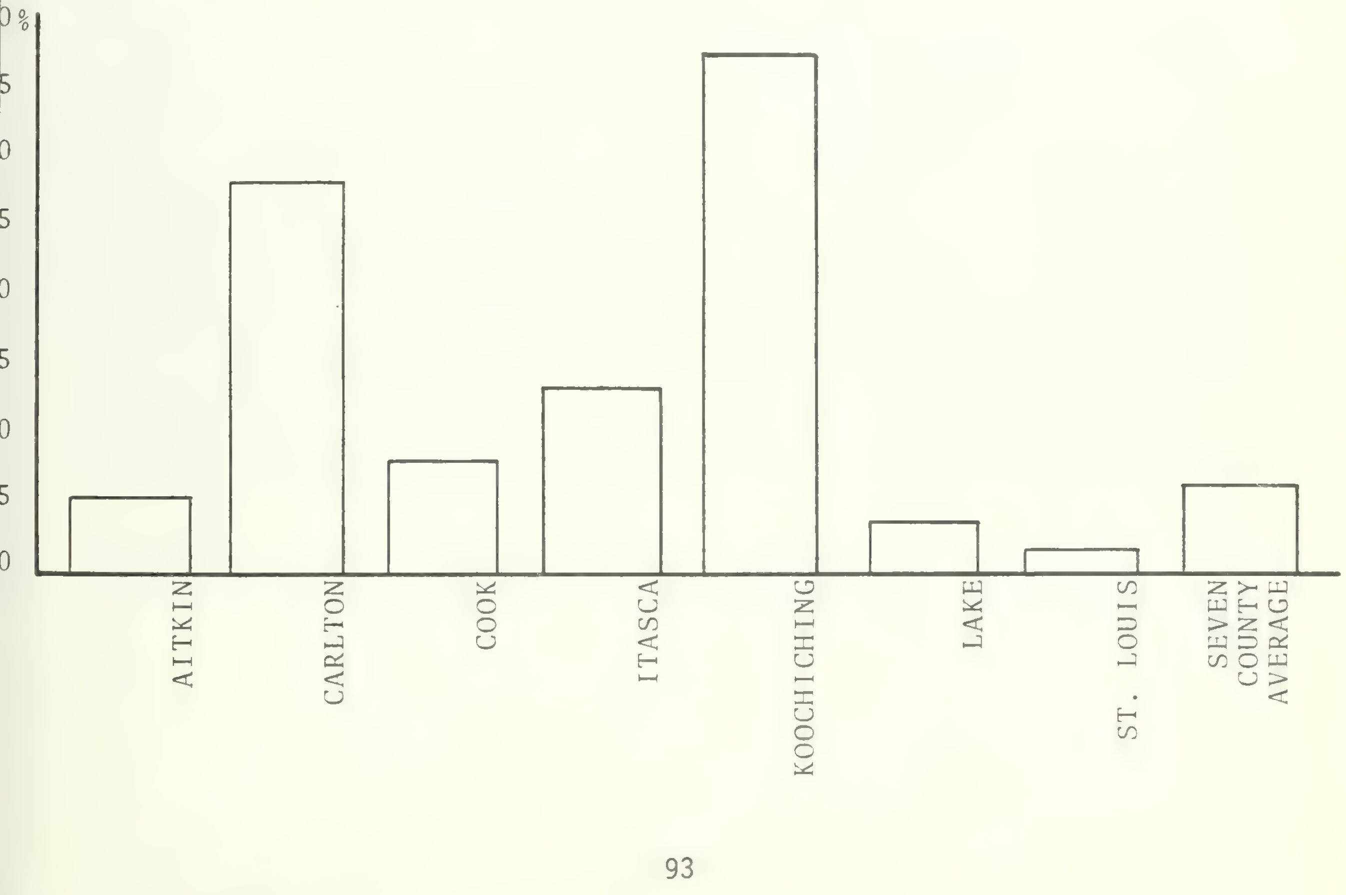
The forest resource in the seven county Arrowhead Region plays an important role in the region's economy. In 1975, two of the seven Arrowhead counties had more than 25 per cent of the labor forest engaged in the primary wood processing industry. (Myers, Kallio, and Friest, 1977).

(Figure 3, Per cent of Labor Forest Engage in Primary Wood Processing in the Arrowhead Region, 1975)

Formal involvement in forestry by the ARDC began in 1973. In January of that year, Raymond O. Benton (Forester, Division of State and Private Forestry, USDA Forest Service) reported to the ARDC for a one-year work assignment with the agency. As a result of Mr. Benton's involvement with the agency, in February of 1974 the ARDC Board of Directors authorized the formation of a Forestry Advisory Committee to assist the Commission with formulating policies on timber resources and land management within the region. This Committee has been very active since its inception in guiding ARDC planners and the agency's Board and Commission in policy matters on Forestry in Northeastern Minnesota. The Committee has broad representation from government, private forest industry and citizens within the Arrowhead Region. Essentially all government agencies that have forest management responsibilities within the region are represented on the ARDC Forestry Committee.

Another significant result of Mr. Benton's work at ARDC was a report that described the forestry resources within the seven county Arrowhead Region based on 1962 NCFES inventory data. This report (1974 Arrowhead Timber Resources) served as a problem analysis and policy guide for the Arrowhead

IGURE 3
ERCENT OF LABOR FORCE ENGAGED IN PRIMARY WOOD PROCESSING IN THE
RROWHEAD REGION. 1975



Commission and Board of Directors. The report also identified some opportunities and constraints for utilization of the timber resource of the region.

There have been additional forestry activities by the ARDC which involved timber inventory in Minnesota. The ARDC worked at both the state and federal levels to obtain funding for the 1977 Forest Inventory in Minnesota Staff of the ARDC were involved in coding the vegetative cover type information for the seven county Arrowhead Region which is represented on the statewide forest cover map that was published by the Minnesota State Planning Agency and NCFES.

Also, a cooperative project between the ARDC, the Minnesota Department of Natural Resources, and the Division of State and Private Forestry (USDA Forest Service) resulted in a publication that relied heavily on NCFES research and forest inventory information. Some of the findings in the publication (1978 Arrowhead Timber Resources Report) are highlighted here.

The purpose of the 1978 Arrowhead Timber Resources Report was to quantify and qualify the timber resource within the seven county region. Quantification of the timber resource was based on preliminary timber inventory data for Minnesota Forestry Survey Units 1 and 2 that was provided by the NCFES. This information was used to describe the supply of timber resources within the region. (Note: The contract period of ARDC involvement in the 1978 study did not allow the option of waiting until the final resource documents on the 1977 Timber Resource Report were prepared and distributed to the public. Therefore, the statistics included in the 1978 Arrowhead Timber Resources document should be revised to reflect the withdrawal of timber and commercial forest land that resulted from the 1978 Federal BWCA legislation; P.L. 95-495).

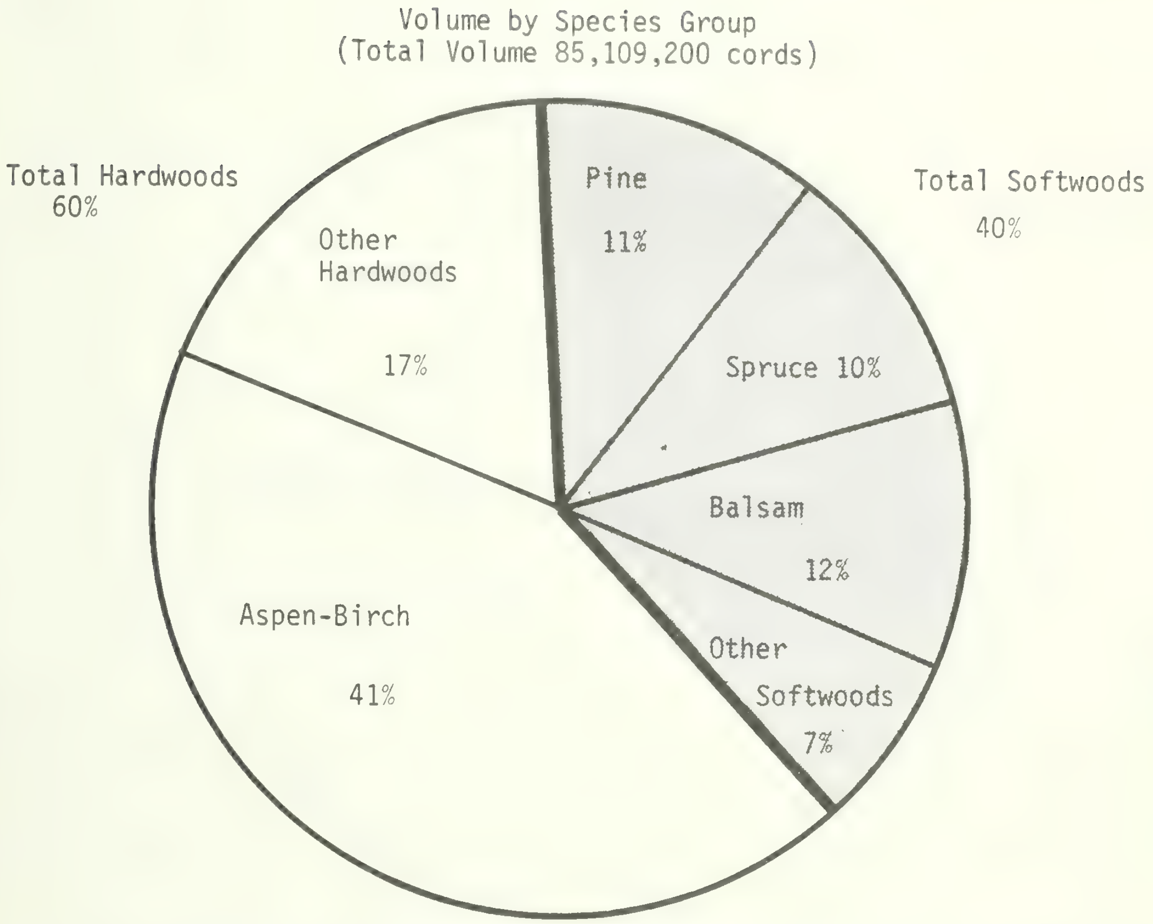
(Figure 4, Arrowhead Region Timber Volume by Species Group, 1977)
(Figure 5, Arrowhead Region Commercial Forest Land by Ownership, 1977)

For historical perspective, between timber inventory dates of 1953-1962 the Arrowhead Region experienced a decline in commercial forest acreage of less than 1 per cent overall. In contrast with this earlier period, between 1962 and 1977 there was a reduction in commercial forest land within the region that exceeded 1 per cent annually. On a species basis there was an approximate 700,000 acre decline within the softwood type alone. The most sought after softwood species (Black Spruce and Jackpine) accounted for more than 400,000 acres of this softwood type reduction. However, there was increase in the 1962-1977 period in the hardwood type in excess of 120,000 acres.

The 1978 Arrowhead Timber Resources Report also evaluated various species components of the region's timber resource. Within both Aspen and Birch in the Arrowhead Region there is a significant portion of the resource in the 40-70 year class.

(Figure 6, Overall Volume by Age Class in the Aspen and Birch Species Within the Arrowhead Region)

Figure 4

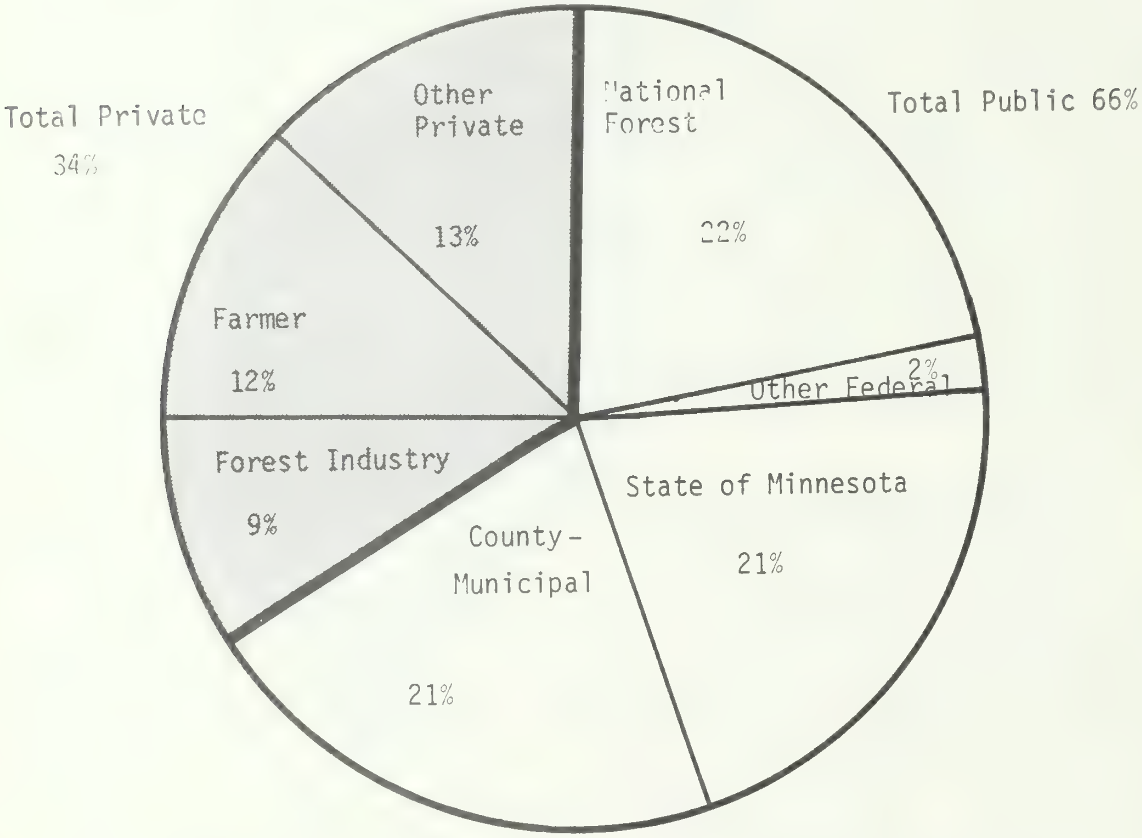


Source: North Central Forest Experiment Station, St. Paul, Minnesota

Figure 5

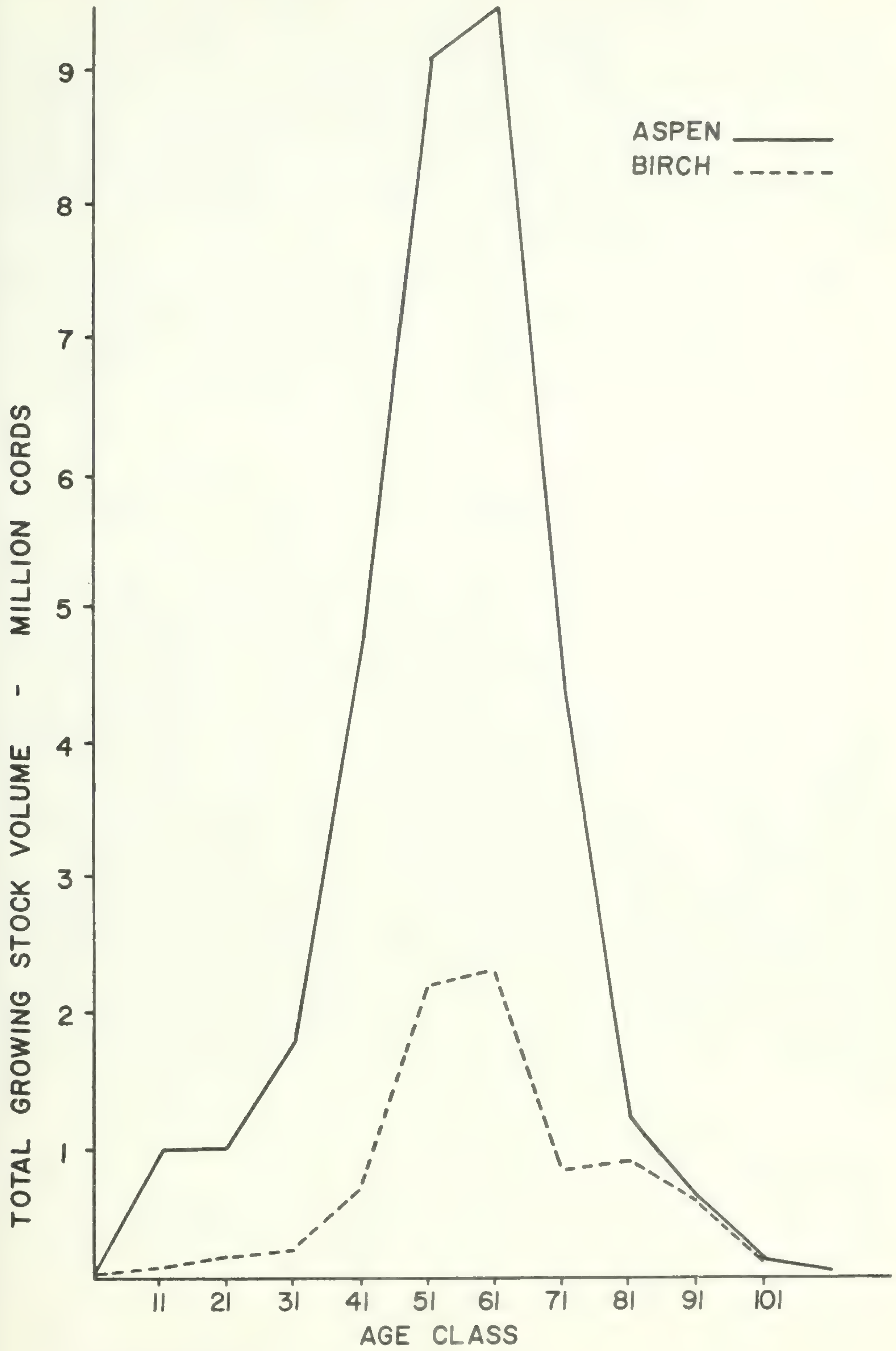
SOURCE: NCFES

Commercial Forest Land By Ownership
(Total Acreage 7,770,310)



Source: North Central Forest Experiment Station, St. Paul, Minnesota

IGURE 6 VOLUME BY AGE CLASS



Our effort to qualify the timber resource within the Arrowhead Region involved an analysis of potential impacts of various governmental programs that could result in withdrawals of timber acreage from productive use within the region. Programs that were evaluated and which had some real potential at the time of the study for affecting future productive use of the timber resource were the Federal Costal Zone Management Program (National Oceanographic and Atmospheric Administration), the U.S. Forest Service RARE II Program (Roadless Area Review and Evaluation Program II), the then pending federal legislation relating to the Boundary Waters Canoe Area (BWCA), and other federal and state programs.

In addition to evaluating possible withdrawals of timber acreage in the region we were interested in qualifying the Arrowhead Region's timber resource based on accessibility and transport costs. To accomplish this we applied a transportation model that was developed at the NCFES in 1972. Bradley (1972). This transportation model (ACCESS) was applied to evaluate the distribution and cost factors associated with transportation of timber resources for various different destinations or mill points.

(Figure 7, ACCESS Measurements for Forest Survey Plots in the Arrowhead Region)
(Figure 8, Hauling Costs for Minnesota Pulpwood by Road Quality and Truck Size, All Products (in dollars per/mile)

Our ACCESS analysis involved measuring the distance from forest survey plots within the Arrrowhead Region to eight different destinations. The distance from the forest survey plot to the destination by various haul road classes was recorded and incorporated into the data for use in the model. The table showing "dollars per cord mile allowances" (See Figure 8) were obtained from U.S. Forest Service, Timber Sale Handbook for Region 9. The hauling equipment options were essentially based on hauling capacity and truck size. Inputs necessary to use this model were 1) computer cards containing road distance measurements for individual plots, 2) a computer tape with forest inventory data for the forest survey plots for the region, and 3) the access computer program. The two examples of tables contained in the report that were produced by the ACCESS model are included in this discussion. Both tables describe the aspen timber resource within the counties of Itasca, Lake, and St. Louis for a Virginia, Minnesota mill site. The first table (See Figure 9) describes the different species that occur within the aspen type. The ACCESS tables provides this information by distance class relative to the destination and also provides a volume-weighted transportation costs according to various truck-trailer combinations (called options on the table). The second table (Figure10) summarizes the distribution of the total aspen species within all timber types relative to the Virginia, Minnesota mill site. Also generated on this table are the volume weighted transportation costs for hauling the aspen resource to the Virginia mill site within each distribution class.

(Figure 9, Distribution of Species Within the Aspen Timber Type Relative to the Virginia, Minnesota Mill Site)
(Figure10, Distribution of Total Aspen Species by Cover Type for Itasca, Lake, and St. Louis Counties Relative to Virginia, Minnesota Mill Site)
(Figure 11, Mill Site; Virginia, Includes Cook, Lake and St. Louis Counties Distribution of Growing Stock Volume by Distance From Mill Site)

Figure 7

ACCESS MEASUREMENTS FOR SURVEY PLOTS IN THE ARROWHEAD REGION

Destination	County Inventory
1. Cloquet	Aitkin
	Carlton
	Itasca
	Lake
	St. Louis
2. Duluth	Aitkin
	Carlton
	Itasca
	Lake
	St. Louis
3. Grand Marais	Cook
	Lake
4. Grand Rapids	Aitkin
	Carlton
	Itasca
	Koochiching
	St. Louis
5. Internation Falls	Itasca
	Koochiching
	St. Louis
6. Isabella	Cook
	Lake
7. Two Harbors	Cook
	Lake
	St. Louis
8. Virginia	Itasca
	Lake
	St. Louis

Figure 8

Hauling Costs for Minnesota pulpwood by road quality and truck size, all products (In dollars per cord-mile)

Road Class	Truck Size-mean load (cords)[1]			
	4	6	8	11
High speed, 45 m.p.h.	.115	.108	.111	.084
Class I, 35 m.p.h.	.168	.150	.155	.119
Class II, 25 m.p.h.	.239	.221	.226	.168
Class III, 16 m.p.h.	.336	.310	.332	.257
Class IV, 8 m.p.h.	.610	.593	.633	.487
Class V, 4 m.p.h.	1.106	1.018	1.194	.916
Fixed Costs (standby, delay,load,unload)	1.77	1.85	1.90	2.48

[1] Truck description--all are equipped with loader; 4 cords, flat bed, 4 by 2, single axle, GVW 28,000 lbs.; 6 cords, flat bed, 6 by 4, tandem axle, GVW 37,000 lbs.; 8 cords, truck tractor, 4 by 2, single axle, with 28-30 ft. platform bed, GVW 59,000 lbs.; 10 cords, truck tractor, 4 x 6, tandem axle, with 30-35 ft. platform trailer, GVW 72,000 lbs.

Source: Handbook of Timber Appraisal, U.S.D.A. Forest Service Reg. 9, Chap. 260, June 1968, Amend. March, 1978.

Figure 9

Distribution of Species Within the Aspen Type

Mill Site: Virginia, MN Includes Counties of Itasca, Lake and St. Louis

```
TYPE:  ASPEN            AREA = 1899000.0 ACRES ÷ NUMBER OF PLOTS  368   =   5160.33  ACRES PER PLOT

ITEM                                                DISTANCE TO MILL  - MILES
                               0-15      16-30      31-45      46-60      61-75      76-90     91-105    106-120    121-135       136+      TOTALS

NUMBER OF PLOTS                   7         36         57         88         86         48         22         17          6          1         368 ←
PERCENT OF TOTAL              1.902      9.783     15.489     23.913     23.370     13.043      5.978      4.620      1.630       .272     100.000
TYPE ACREAGE                36122.3   185771.7   294138.6   454108.7   443788.0   247695.7   113527.2    87725.5    30962.0     5160.3   1899000.0
CLASS MEAN TOTAL
DISTANCE - MILES               11.0       24.1       38.0       53.2       67.6       81.1       96.7      112.9      126.0      135.6
CLASS MEAN BY
ROAD QUALITY
1-PAVED                         9.2       20.4       34.8       49.2       61.2       72.0       91.4      106.2      123.4      117.2
2-GRAVELED                      1.4        2.6        2.2        2.8        5.0        8.0        4.4        6.0        1.6       16.0
3-ALL WEATHER                     0          0         .0         .1         .1         .0         .0         .1          0        2.2
4-DRY WEATHER                     0         .0         .0          0         .2          0         .1          0          0          0
5-WINTER ROADS                    0         .0         .0         .1         .1         .0          0          0          0          0
6-CROSS COUNTRY                  .4        1.1         .9        1.0        1.0        1.0         .8         .7        1.0         .2

TRANSPORT COST PER CORD - NOT WEIGHTED BY VOLUME

  OPTION  1  COST             3.533      5.805      7.178      9.060     10.895     12.537     13.963     15.730     17.352     18.684
  OPTION  2  COST             3.467      5.553      6.822      8.556     10.236     11.733     13.065     14.687     16.201     17.363
  OPTION  3  COST             3.643      5.909      7.212      9.036     10.795     12.356     13.737     15.409     17.049     18.124
  OPTION  4  COST             3.808      5.535      6.518      7.900      9.236     10.422     11.458     12.723     13.962     14.782

SPECIE VOLUMES FOLLOWED BY VOLUME WEIGHTED TRANSPORT COSTS PER CORD

JACK PINE    VOL:                 0   100626.4     8019.1    97401.2   120142.7    83122.5          0          0          0          0    409311.9
  OPTION  1  COST                 0      5.164      7.369     10.079     13.096     10.730          0          0          0          0
  OPTION  2  COST                 0      4.963      7.016      9.490     12.225     10.106          0          0          0          0
  OPTION  3  COST                 0      5.251      7.504     10.113     13.048     10.561          0          0          0          0
  OPTION  4  COST                 0      5.033      6.752      8.736     10.975      9.037          0          0          0          0

RED PINE     VOL:                 0    36973.7    22143.0    56417.8    73818.5    79804.4    37830.4          0          0          0    306987.8
  OPTION  1  COST                 0      4.995      7.323     11.969     11.293     11.991     12.996          0          0          0
  OPTION  2  COST                 0      4.807      6.962     11.197     10.581     11.248     12.195          0          0          0
  OPTION  3  COST                 0      5.075      7.312     12.127     11.121     11.833     12.756          0          0          0
  OPTION  4  COST                 0      4.898      6.585     10.292      9.485     10.017     10.699          0          0          0

WHITE PINE   VOL:                 0    49786.8    25502.3   107081.9    97019.3    16492.4    22127.5          0          0          0    318010.3
  OPTION  1  COST                 0      5.323      8.336      9.796     11.907     11.502     13.041          0          0          0
  OPTION  2  COST                 0      5.117      7.888      9.209     11.139     10.809     12.236          0          0          0
  OPTION  3  COST                 0      5.416      8.493      9.748     11.764     11.310     12.817          0          0          0
  OPTION  4  COST                 0      5.155      7.506      8.451      9.991      9.609     10.748          0          0          0

BALSAM       VOL:           48796.0   274178.4   373643.7   491644.9   427290.5   293235.5   169439.3   123352.4    74009.4          0   2275590.3
  OPTION  1  COST             3.607      5.044      7.286      9.173     10.522     12.497     14.162     15.396     17.817          0
  OPTION  2  COST             3.536      4.861      6.923      8.659      9.892     11.705     13.260     14.384     16.634          0
  OPTION  3  COST             3.724      5.134      7.323      9.146     10.405     12.335     14.006     15.084     17.578          0
  OPTION  4  COST             3.870      4.940      6.602      7.986      8.937     10.404     11.665     12.474     14.370          0

WHITE SP.    VOL:            3622.5    32850.6    33903.3   117051.7   129467.4    45204.5    50313.2    56010.2          0          0    468423.4
  OPTION  1  COST             3.585      4.925      9.550      9.330     11.362     13.602     14.684     15.328          0          0
  OPTION  2  COST             3.517      4.753      8.996      8.756     10.664     12.652     13.733     14.315          0          0
  OPTION  3  COST             3.704      5.009      9.724      9.244     11.303     13.288     14.551     14.989          0          0
  OPTION  4  COST             3.855      4.843      8.451      8.075      9.631     11.149     12.086     12.402          0          0
```

Figure 9 (cont.)

```
                              ASPEN

  ITEM                                                DISTANCE TO MILL  - MILES
                          0-15     16-30     31-45     46-60     61-75     76-90    91-105   106-120   121-135      136+      TOTALS

  BLACK SP.     VOL!    6016.9    6378.2   44347.8   63745.5  107845.7   55308.4   17803.1         0         0         0    301445.6
    OPTION  1  COST        3.669     5.566     6.754     8.990    11.732    13.967    16.782         0         0         0
    OPTION  2  COST        3.592     5.336     6.434     8.493    10.982    12.992    15.640         0         0         0
    OPTION  3  COST        3.782     5.668     6.780     8.971    11.646    13.710    16.751         0         0         0
    OPTION  4  COST        3.914     5.350     6.187     7.849     9.899    11.474    13.786         0         0         0

  N. WHT. CED.  VOL!         0    9660.1    3663.8   63172.7   18226.3         0   55189.7         0         0         0    149912.6
    OPTION  1  COST            0     5.112     6.487     8.499    13.017         0    13.669         0         0         0
    OPTION  2  COST            0     4.926     6.189     8.045    12.099         0    12.807         0         0         0
    OPTION  3  COST            0     5.181     6.501     8.455    12.801         0    13.418         0         0         0
    OPTION  4  COST            0     4.972     5.973     7.451    10.803         0    11.206         0         0         0

  TAMARACK      VOL!         0         0         0    8958.3   39858.4    4628.8    4597.9    8215.2    7611.5         0     73870.1
    OPTION  1  COST            0         0         0     8.586    12.356    11.643    13.985    18.228    17.271         0
    OPTION  2  COST            0         0         0     8.129    11.592    10.943    13.092    16.945    16.125         0
    OPTION  3  COST            0         0         0     8.561    12.395    11.448    13.702    17.970    16.941         0
    OPTION  4  COST            0         0         0     7.532    10.462     9.709    11.422    14.702    13.879         0

  OAK           VOL!         0    3405.8    2017.7    5026.2    7900.5    2977.5         0    9876.9         0         0     31204.5
    OPTION  1  COST            0     5.065     7.456     9.377     9.933    11.325         0    14.977         0         0
    OPTION  2  COST            0     4.884     7.099     8.850     9.361    10.646         0    14.020         0         0
    OPTION  3  COST            0     5.199     7.462     9.356     9.784    11.155         0    14.655         0         0
    OPTION  4  COST            0     4.992     6.702     8.142     8.454     9.494         0    12.135         0         0

  ELM-ASH-COT.  VOL!         0    7988.2   59059.9  139901.6  187779.1   67497.1   81337.1   78220.2   10351.6         0    632134.8
    OPTION  1  COST            0     4.682     6.553     8.714    10.069    13.400    13.427    15.606    17.470         0
    OPTION  2  COST            0     4.519     6.251     8.238     9.489    12.480    12.589    14.586    16.316         0
    OPTION  3  COST            0     4.750     6.589     8.671     9.948    13.115    13.207    15.301    17.226         0
    OPTION  4  COST            0     4.649     6.041     7.618     8.581    11.013    11.046    12.635    14.100         0

  MAPLE-BASS.   VOL!         0    2729.8   26457.0   74365.5   55762.5   36457.7   14552.1    5924.1         0         0    216248.6
    OPTION  1  COST            0     5.887     6.964     9.067    10.245    12.476    13.397    14.977         0         0
    OPTION  2  COST            0     5.630     6.630     8.562     9.648    11.644    12.566    14.020         0         0
    OPTION  3  COST            0     5.975     6.968     9.050    10.148    12.211    13.160    14.655         0         0
    OPTION  4  COST            0     5.584     6.327     7.910     8.742    10.319    11.006    12.135         0         0

→ ASPEN         VOL!  192557.6 1235702.0 1922427.9 3320948.5 3517066.7 1308529.7  870325.1  866434.2  226466.1         0  13460457.7 ←
    OPTION  1  COST        3.645     5.421     7.314     9.041    11.095    12.751    13.798    15.451    17.219         0
    OPTION  2  COST        3.570     5.203     6.948     8.535    10.416    11.915    12.923    14.437    16.084         0
    OPTION  3  COST        3.759     5.496     7.361     9.012    11.015    12.532    13.589    15.127    16.936         0
    OPTION  4  COST        3.897     5.216     6.633     7.883     9.407    10.559    11.342    12.505    13.876         0

  BIRCH         VOL!         0  139550.7  384604.3  505113.4  480405.7  305321.0  245327.1  220175.6         0         0   2280497.7
    OPTION  1  COST            0     5.177     7.315     8.994    10.788    12.443    13.405    17.767         0         0
    OPTION  2  COST            0     4.980     6.947     8.503    10.133    11.654    12.561    16.482         0         0
    OPTION  3  COST            0     5.267     7.342     8.988    10.665    12.279    13.174    17.366         0         0
    OPTION  4  COST            0     5.042     6.617     7.865     9.136    10.361    11.024    14.246         0         0

  BALSAM POP.   VOL!         0   23907.8  146305.6  540719.6  405679.0  224948.9   51061.4  107871.5   30239.5         0   1530733.3
    OPTION  1  COST            0     5.751     7.470    10.270    10.455    12.578    13.856    15.754    18.418         0
    OPTION  2  COST            0     5.502     7.089     9.676     9.840    11.760    12.984    14.717    17.189         0
    OPTION  3  COST            0     5.789     7.481    10.345    10.373    12.336    13.690    15.465    18.218         0
    OPTION  4  COST            0     5.438     6.722     8.903     8.911    10.405    11.422    12.765    14.862         0

  VOLUME TOTAL        250993.1 1923738.6 3052095.5 5591548.7 5668262.1 2523528.5 1619903.8 1476080.3  348678.1         0 22,454,828.7
```

Figure 10

Distribution of Total Aspen Species by Cover Type for a Virginia, MN Millsite
Cook, Lake, and St. Louis Counties

SPECIE: ASPEN

ITEM	DISTANCE TO MILL - MILES										
	0-15	16-30	31-45	46-60	61-75	76-90	91-105	106-120	121-135	136+	TOTALS
TYPE VOLUMES											
PINE	0	102618.1	149068.5	58088.4	320712.9	138998.1	116577.7	0	0	0	886063.8
BALSAM	36654.7	125769.3	164392.8	35105.7	96267.6	48337.0	0	2867.5	22922.1	0	532316.7
SPRUCE	0	0	86458.5	17460.3	61790.7	22518.1	0	28664.9	0	0	216892.5
OTHER SFTWDS	0	0	0	25765.4	26753.5	26581.8	0	0	1976.2	0	81076.9
ASPEN	192557.6	1235702.0	1922427.9	3320948.5	3517066.7	1308529.7	870325.1	866434.2	226466.1	0	13460457.7
BIRCH	31484.2	109958.3	130255.9	139534.9	292891.4	414519.6	26331.0	23141.3	0	0	1168116.7
OTHER HDWDS	28698.2	21690.5	22569.2	108452.6	88515.1	64851.9	77252.0	13270.2	49411.0	0	474710.5
TOTAL VOLUME	289394.6	1595738.1	2475172.8	3705355.7	4403997.8	2024336.2	1090485.8	934378.2	300775.4	0	16,819,634.8
OVERALL-VOLUME WEIGHTED TRANSPORT COSTS: $/CORD											
OPTION 1 COST	3.866	5.419	7.470	9.004	11.128	13.118	13.968	15.494	17.561	0	
OPTION 2 COST	3.775	5.202	7.087	8.502	10.445	12.260	13.075	14.477	16.398	0	
OPTION 3 COST	4.005	5.493	7.514	8.975	11.043	12.954	13.756	15.175	17.299	0	
OPTION 4 COST	4.087	5.214	6.751	7.854	9.429	10.883	11.472	12.541	14.155	0	
PERCENT OF GROWING STOCK:											
	1.7	9.5	14.7	22.0	26.2	12.0	6.5	5.6	1.8	0	100.0

Figure 11 describes the cumulative and discrete distribution of softwoods and hardwoods relative to the Virginia Mill Site by distance class.

We also wanted to analyze demand for the timber resource within the Arrowhead Region. In our search for this information, we discovered the industries contacted were not comfortable with supplying ARDC with their utilization information. However, the industries were comfortable with providing this information to researchers at the NCFES. As a result, it was necessary to rely on staff at NCFES for information on the demand and utilization of timber resources within the Arrowhead Region.

(Figure 12, Arrowhead Region Average Saw Timber Stumpage Price, All Agencies; County State National Forest and Indian)
(Figure 13, Average Pulpwood Stumpage Price, All Agencies; County State National Forest and Indian)

By utilizing information provided by NCFES personnel, we were able to include in the report data on the pattern of stumpage price behavior within this time frame of 1965-1977. In terms of pulpwood production, the Arrowhead Region historically has provided a large share of pulpwood produced in the State of Minnesota. Utilizing information that has been collected by research staff at NCFES discovered that 74 per cent of all pulpwood produced in Minnesota in 1975 was obtained from counties in the Arrowhead Region. There was a 50 per cent increase in total timber harvested in 1975 as compared to 1960.

(Figure 14, 1975 Pulpwood Production in the Arrowhead Region by County)
(Figure 15, Arrowhead Region, Wood Harvested by County 1960-1976)

Current Work at ARDC that is reliant on NCFES Inventory Data and Research

At the present time, the ARDC is currently under contract to the U.S. Forest Service to evaluate wood energy within the Arrowhead Region. This study essentially involves an analysis of wood energy potential from non-merchantable species and wood residues on the federal ownership within the Superior National Forest and an analysis non-industrial private forest lands in the region regarding timber supply and wood energy. To accomplish the first aim of this research we are evaluating the use of the STEMS sub-routine of FREP (STEMS= Stand and Tree Evaluation Modeling System; FREP=Forest Resources Evaluation Program) that has been developed at the NCFES timber inventory data to develop estimates of energy potential from non-merchantable species on the National Forest ownership within the Superior National Forest. We will also be conducting an analysis of potential energy available from topwood and limbs remaining after commercial harvest on timber (using methods developed by the U.S. Forest Service North East Forest Experiment Station).

It should be evident through this discussion that by simple necessity, regional planning in forested areas of Minnesota is reliant on timber inventory information produced by the NCFES.

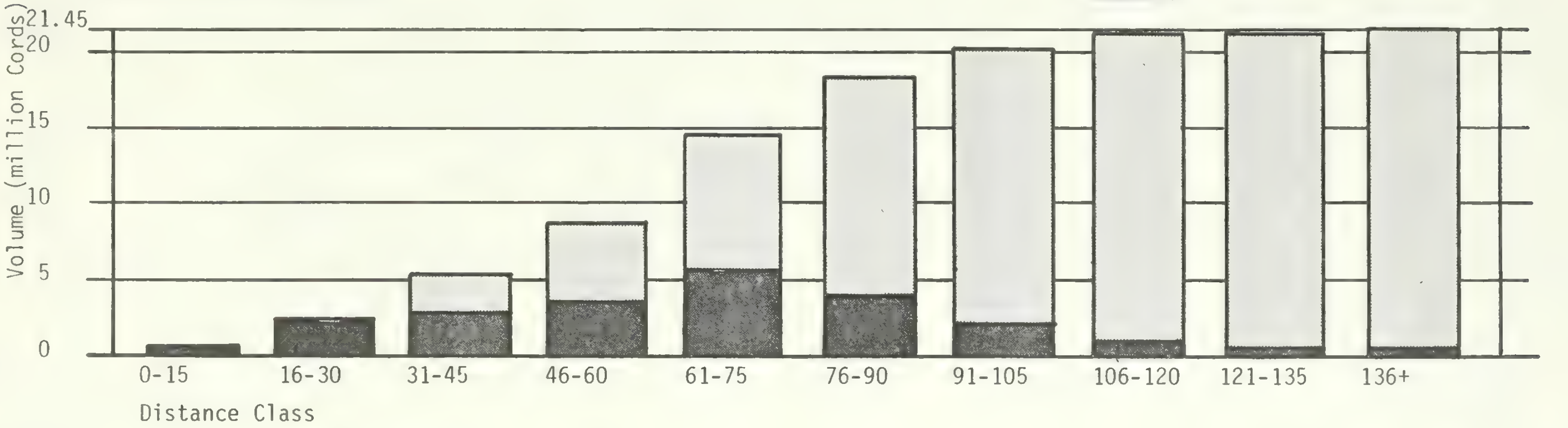
Comment on Continuing Concerns on Forestry Inventory Information and NCFES Research

The Forestry Advisory Committee of the ARDC has adopted a number of goal

Figure 11

Mill Site: Virginia; includes Cook, Lake and St. Louis Counties
Distribution of Growing Stock Volumes by Distance from Mill Site

Figure 5a Total Softwoods



Total Hardwoods

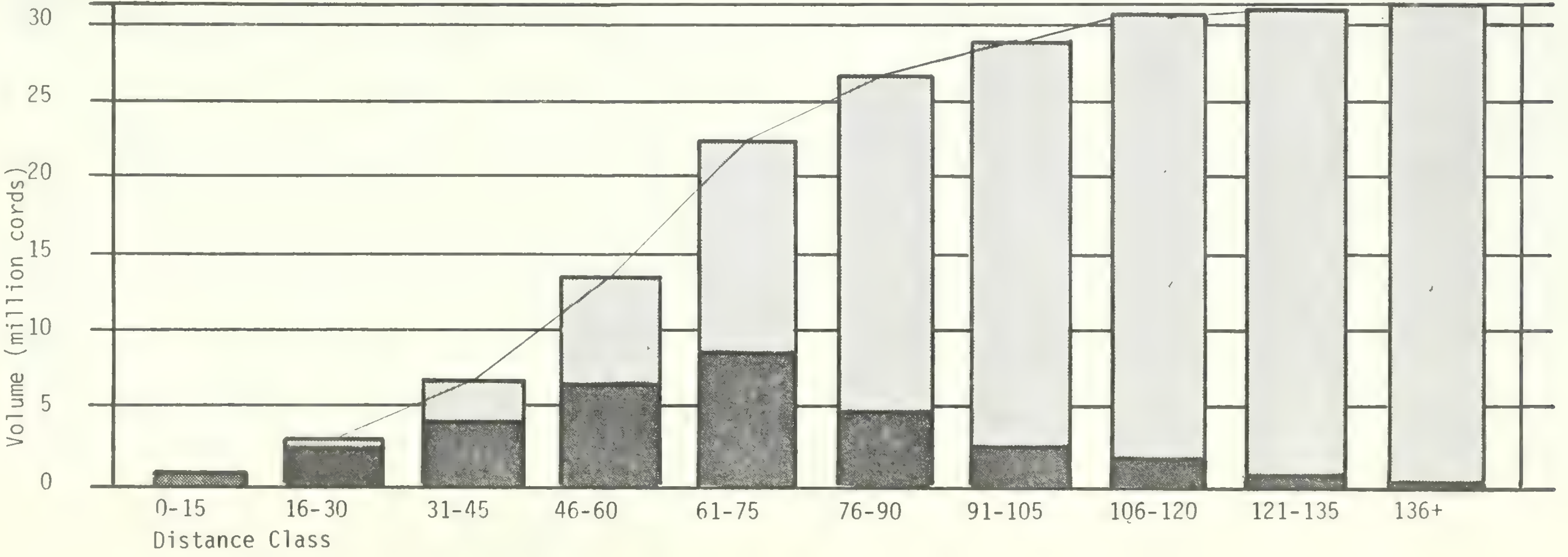


Figure 12

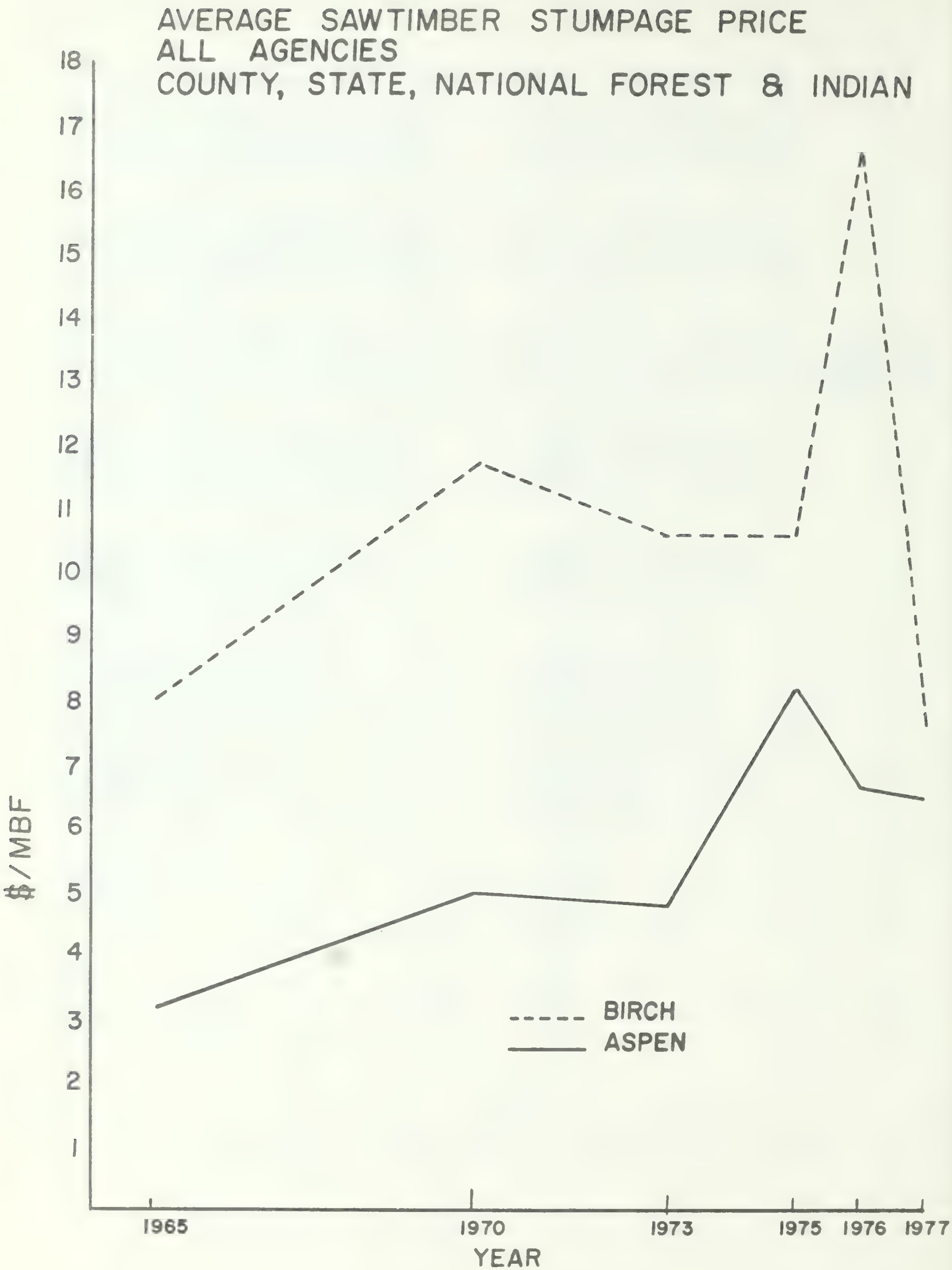

AVERAGE SAWTIMBER STUMPAGE PRICE
ALL AGENCIES
COUNTY, STATE, NATIONAL FOREST & INDIAN
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
$/MBF
BIRCH
ASPEN
1965
1970
1973
1975
1976
1977
YEAR

Figure 13

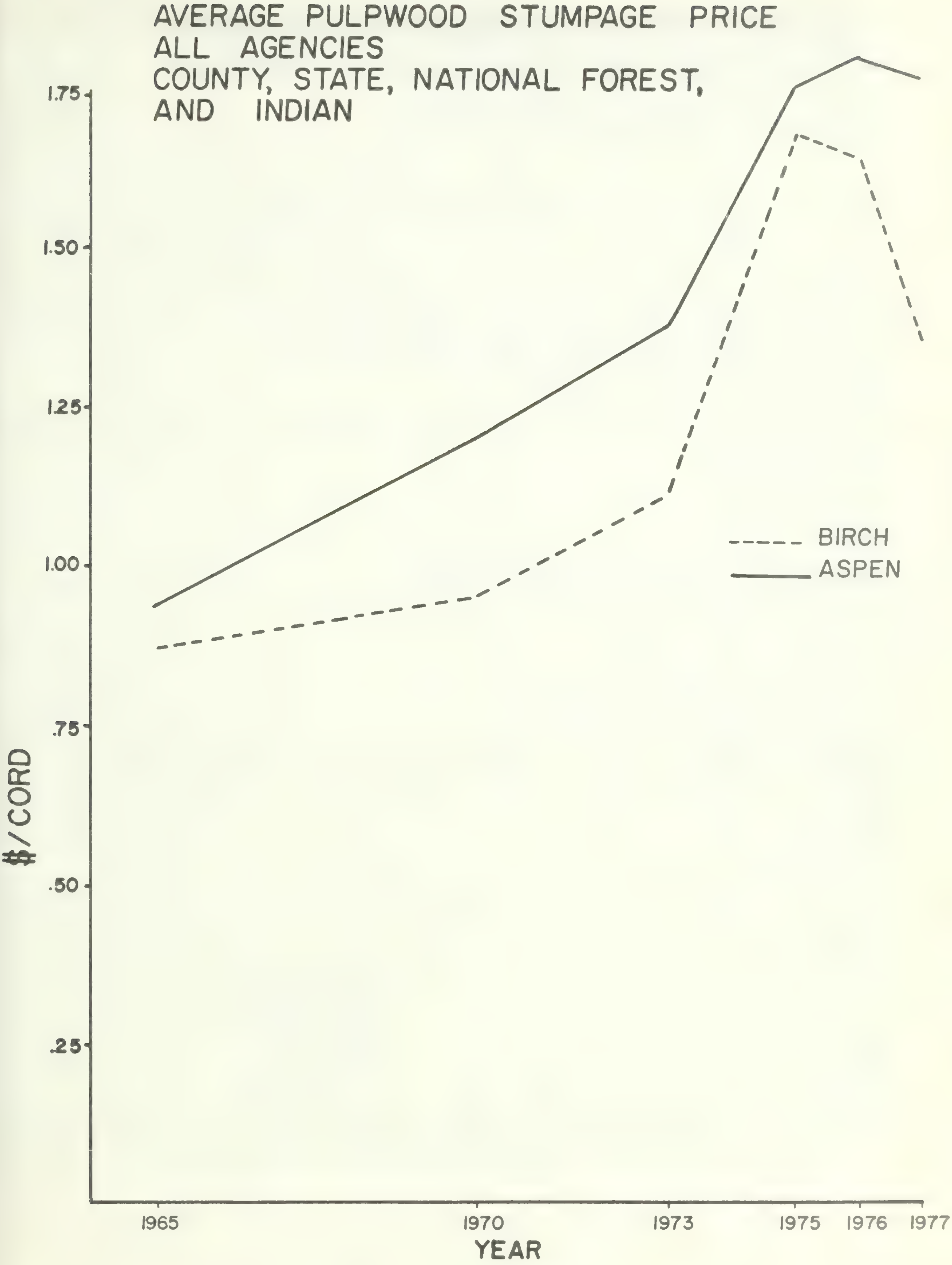

AVERAGE PULPWOOD STUMPAGE PRICE
ALL AGENCIES
COUNTY, STATE, NATIONAL FOREST, AND INDIAN
1.75
1.50
1.25
1.00
.75
.50
.25
$/CORD
1965
1970
1973
1975
1976
1977
YEAR
BIRCH
ASPEN

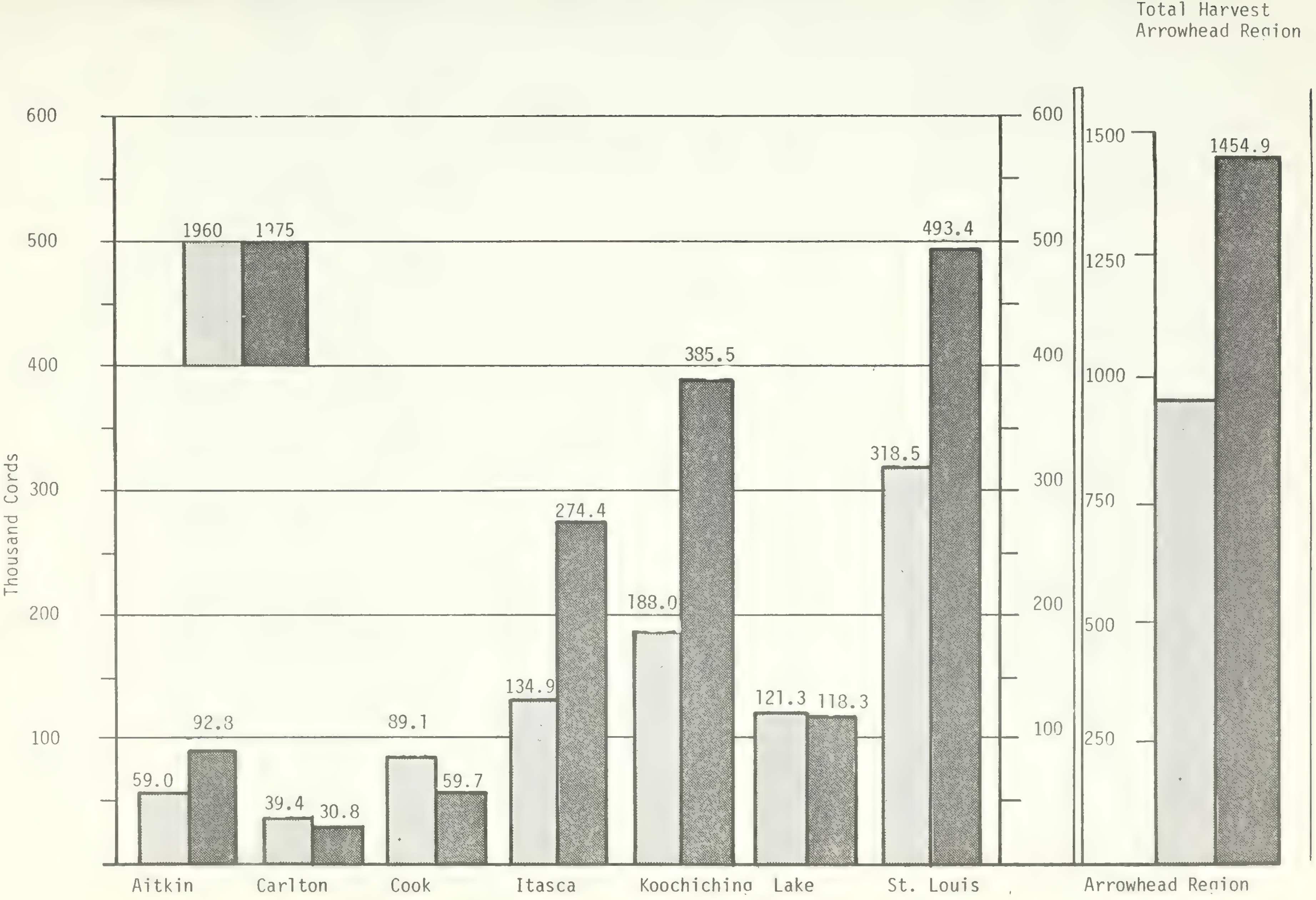
Figure 14

1975 PULPWOOD PRODUCTION IN THE ARROWHEAD REGION BY COUNTY

Source: U.S. Forest Service Resource Bulletin NC-34 (Blyth, Hahn)
(Cords)

	Aitkin	Carlton	Cook	Itasca	Koochi-ching	Lake	St. Louis	Reg. Total	State Total	Ratio: Region /State
Balsam Fir	662	524	1479	26057	39643	12009	22796	103170	121296	.8505
Jack Pine	1333	1938	3780	7399	12558	21052	64191	112251	180543	.6217
Red Pine	-	500	74	741	1823	950	3429	7517	10790	.6967
White Pine	-	-	-	742	2540	-	3688	6970	7386	.9437
Spruce	1468	262	8447	16055	75689	24670	43795	170386	202004	.8435
Tamarack	4113	259	-	5312	23458	68	6842	40052	56266	.7118
Aspen	34528	17338	15915	56522	126238	13420	184212	448173	615995	.7276
Balsam Poplar	-	-	-	220	6107	-	3701	10028	10725	.9350
White Birch	2515	3133	-	2614	2947	2036	7682	20927	35474	.5899
Yellow Birch and Other Hardwoods	-	-	-	-	-	-	-	-	5	-
Elm	-	-	-	-	692	-	-	692	733	.9441
Hard Maple	-	19	-	24	14	-	8	65	200	.3250
Soft Maple	-	8	-	5	17	-	35	65	79	.8228
Red Oak	5541	376	-	-	693	-	-	6610	9703	.6812
Total Cords	50160	24357	29695	115691	292419	74205	340379	926906	1251254	.7408

Figure 15 Wood Harvested by County - 1960 - 1976



Source: North Central Forest Experiment Station, St. Paul, Minnesota

statements that relate directly to forestry inventory and research. One of these goals states a need for "an integrated information system that determines and predicts needs and demands affecting area forests, and which provides adequate data for identifying and evaluating research management alternatives." A further refinement of this statement is a policy that "comprehensive, coordinated, and current information on the forest resources of the region should be available for all public and private interests." Another policy relates to the need to "better coordinate and provide the necessary funding and manpower necessary to collect, analyze, and interpret forest inventory data at more frequent intervals." Some operational concerns that the ARDC Forestry Committee expressed through the goal statements relate to improved useability of forest inventory data; "inventory data collected by all agencies should be standardized to permit data storage for affective retrevial; increase utilization of FREP or similar models to update forest research data between inventories; implement FREP or similar evaluation systems to predict the effect of management and harvesting schedules in future resources and availability."

A discussion of forest inventory with reference to regional planning for the economic and social welfare in the population of the Arrowhead Region follows. We feel there is a need to develop a consolidated information base that would include forest information as well as all of the other social, economic and demographic data that we need to plan for resource development on a regional basis.

From a geographic standpoint, we have been elated when NCFES research efforts have been done on a regional basis (i.e. consistent with Minnesota Region boundaries). A good example of past NCFES research efforts of this type is a 1978 study that analyzed the income generated in the primary forest industry in the Arrowhead Region (Myers, Kallio, and Friest, 1975). We feel that current NCFES proposals to update and expand the forestry sector on the input-output tables for the Arrowhead Region would be a significant improvement for our planning purposes. We also believe a NCFES proposal to develop a regional timber industry component for a business index for the Arrowhead Region has very positive potential for regional planning.

In summary, for regional planning purposes in Minnesota, we need accurate information on the forest resource in the state. From our experience at ARDC, we feel the NCFES is the best qualified and most appropriate agency to provide this resource data. As evidenced by the various testimonies presented before Congress prior to passage of the 1978 BWCA legislation, we must have accurate resource information to develop intelligent responses to various government and private programs that have the potential to affect the utilization and supply of the timber resource. We feel an expanded effort at maintaining current forest inventory information, such as that possible through the use of FREP, will assist regional planners in evaluating changing resource and economic conditions in forested areas in Minnesota. Finally, we feel there is a tremendous opportunity for increasing technology transfer of NCFES research and timber inventory information for greater public use and benefit.

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FUTURE RESOURCE INVENTORIES

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Two major events occurred recently that will profoundly affect all future resource inventories. The first and most visible of these occurrences was the passage in 1974 of the Resources Planning Act (PL93-378)(RPA). The net effect of RPA for the USDA Forest Service Resource Evaluation Units in the country is to expand their timber-oriented inventories to provide more complete multi-resource information. The second event was the double-digit inflation that has occurred in our economy and has severely eroded our productivity per dollar.

Alternate Data Sources

We will continue to rely on the active cooperation and participation by the States, universities, industries, consultants, environmental groups, and the many others that are concerned about our natural resources. The efforts of these organizations will continue to provide the input necessary for successful inventories. The continuation of the current economic situation will make every new resource inventory a difficult compromise at best. Our resource evaluation unit clearly sees the mandate of RPA as a need to improve methods of ensuring a fair analysis of our priorities in the future. We can no longer consider timber as the sole driving force of our resource inventories. At the same time we are forced to realize that we can only include so much in our inventories design.

However, we must seek alternate sources of resource information whenver possible and derive methods of extracting more information from existing resource data.

To fulfill our responsibility dictated by RPA, and remain within our limited budget, we will have to devise new ways to collect data. Following are some of the innovative ideas that we feel will make the greatest change in the way we will collect, compute, retrieve, and analyze resource inventory data in the future:

Bayesian Estimators - Bayesian Estimation is a statistical procedure that uses data from past and/or adjacent surveys to improve the precision and accuracy of inventory statistical estimates. Preliminary tests indicate that present levels of accuracy for county and unit volume estimates may be improved by 10 to 15 percent or more by using Bayesian procedures. Or, if present levels of accuracy are acceptable, these estimates could be derived by measuring 10 to 15 percent fewer plots. This research is being conducted cooperatively between the North Central Forest Experiment Station and the University of Minnesota and is headed by Dr. Alan Ek of the College of Forestry at the University.

Management Information Systems - We plan to create System 2000 data bases for all future resource inventories in our region. This system of data bases will allow researchers and analysts with limited computer programming knowledge access to the inventory data at low cost.

We are currently redesigning our data base structure to improve its efficiency and enhance regional resource analysis capabilities. With the addition of predefined table generating programs, many special requests in the future will be handled without the services of experienced programmers.

Computer Digitizing - We are testing a new computer digitizing system that determines the coordinates of our field plot locations to within 10 meters on United States Geological Survey quad maps and records these coordinates in the Universal Transverse Mercator (UTM) System. This process in conjunction with System 2000 and the Bayesian procedures could allow us to acquire precise statistics for local areas. For example, we could determine the available resource within 100 miles of Bemidji, Minnesota. This information in conjunction with plot data regarding stand operability, such as distance to road, slope, aspect, volume class, etc., should prove useful in analyzing how much of that resource is economically available. In another application, tie-in of UTM's with Landsat data could greatly improve image registration accuracy, which in turn could provide better land change information.

Graphics - Computer graphics is another area in which we feel we are making significant progress. To a researcher or analyst a picture can often be worth a thousand tables when it comes to assessing what's happening to the resource. We are striving to link graphics capabilities with System 2000 to provide greater flexibility in data retrievals for users, researchers, and analysts.

Land Change Analysis - The analysis of what's happening to the resource on the ground poses some perplexing problems for inventory designers. What happened, where did it happen, and most importantly how will we know that it happened? Landsat satellite imagery and low altitude photography are the major methods being researched in this area. To date our experiences with Landsat have not been encouraging but we are convinced that with time and technology imagery will yield the land change information we need at low cost. Unfortunately the critical element of time dictates that we also investigate an alternative approach. The most promising one appears to be low-altitude 35mm photography. The basic premise of this research effort is that conventional photography is not well adapted due to limitations of resolution, contrast, and scale to meet the need for detailed information pertaining to detection of change. This becomes particularly critical when the date of the conventional photography is not reasonably close to the date of fieldwork. Low-altitude photography may be a time-and cost-efficient method to eliminate this problem.

An added bonus of the low-altitude photography may be the presence of easily obtained data relating to other nontimber resources. In any event, it appears that the ability to successfully detect change will greatly enhance the application of forest growth simulation in inventory design.

Forest Growth Simulation - The Forest Resources Evaluation Program (FREP) is the most exciting of all the new inventory enhancement techniques. We are currently working with the development team to incorporate the individual tree growth projection system (STEMS), part of this computerized modelling system, into our resource inventory design. Although several alternative sampling techniques have been discussed, the use of growth modeling seems to have the most appeal from an intuitive and practical standpoint. Growth modeling doesn't require complicated mathematical computations and by using individual tree simulation it retains the integrity of the original inventory tree list. This latter fact conveniently allows summarization of the inventory data in the traditional manner.

The basic concept of the growth model inventory design involves stratifying our sample into undisturbed and disturbed plots (therefore, accurate land change information is needed). All of the disturbed plots would be remeasured along with a subsample of the undisturbed plots. Undisturbed plots that were not remeasured would be updated by the projection system. The cost of updating a forest plot by projection is about 15 cents as compared to $250 for relocating and remeasuring a permanent sample plot on the ground. The total reduction in the number of field plots measured with such a design could add up to 30 percent or more.

All of the intricate details of incorportaing a projection system into our inventory design have not yet been worked out, but we have already begun to use parts of the growth projection process. To date we have planned or carried out seven resource inventory and analysis projects using modified versions of the FREP tree growth projection system. These projects reflect our belief that growth simulation will become an indispensible tool in future resource inventories. The following brief summaries of these projects indicate many of the potential uses we see for growth modeling:

(1) The 1969 Chippewa National Forest inventory data were updated with removals to 1977 so that they would coincide with the date of the plot work carried out in the remainder of the Northern Pine Survey Unit of Minnesota.

(2) Predicted timber yields were computed for northern Minnesota for the decade 1977-1986 using two selected sets of harvest criteria (Jakes and Smith 1980a). More work is planned in this area using the growth projection system to look at the long term effects on timber yields using different management strategies.

(3) Treatment opportunities in Minnesota were studied. (Jakes and Smith 1980b). Statewide needs for restocking and stand conversion were also analyzed. Much effort will be devoted to treatment opportunities during the coming years due to the increasing demands being made on our forest land. Of particular interest is the economic impact of restocking nonstocked and poorly stocked stands.

4) The 1968 Wisconsin survey was updated to the year 1979 without new photos or fieldwork (Raile and Smith, 1980). We feel these updated statistics are reasonable estimates of the current resource in Wisconsin. This type of updating between major resource inventories may be one of the more important uses of forest growth simulation.

5) An upper Lake States regional report will be produced using a modified version of the projection system. The main emphasis of this report will be on the resource situation in the heavily wooded northern portions of Minnesota, Wisconsin and Michigan.

6) The timber resource statistics for the Hiawatha National orest will be updated so that the eastern portion of Michigan's Upper Peninsula will be reported for a common point in time.

7) An integrated growth model inventory design is currently being tested for possible use in the fourth Wisconsin resource inventory. This new inventory design, if successful, could dramatically improve the timeliness of State and regional reporting of resource information as well as substantially reduce field inventory work and therefore the cost of the inventory.

Although much emphasis is being placed on the role of growth modeling in field inventory design, many of the previous examples demonstrate that its use as an analysis and planning tool will be equally important.

Nontimber Resources

The demand for nontimber--water, wildlife, and recreation--resource information seems to increase at an exponential rate and collection of such information will likely play a more important role in future inventories. We have always collected some data about nontimber resources because all components of the forest are ecologically linked. Some minor expansions of existing data may provide a wealth of new information once we better understand the interrelations of forest ecosystms as they relate to resource analysis.

For example, in the last survey of Minnesota information on distance to water was collected. More specific information about whether the water is a lake, river, stream, pond, etc., and perhaps a size classification will be collected in the future. This added information, when coupled with the other forest and water data currently collected, may yield much information about the condition and extent of forest watersheds.

Demand for information about wildlife habitat is constantly increasing. In the current Michigan and North Dakota surveys we are collecting data on shrub and herbaceous species of plants. This information will help to better define wildlife habitat within our forests and where these habitats are located. A cooperative study is currently being conducted at the University of Minnesota in which an assessment of existing data as well as new data needs for defining habitat characteristics is being reviewed. One area of wildlife data collection in which we perceive a need for more research is in finding economical ways to measure interspersion and edge without drastically altering current inventory design. Low-altitude photography might provide this information.

With current energy shortages and the high cost of gasoline, more emphasis has been placed on the recreational potential of local forested areas. In the last Minnesota survey we collected information on distance to road and the general slope, aspect, and position of each forest sample plot. If we know that cross country skiers enjoy skiing through 35-year-old aspen forests containing gentle slopes, we could produce information on how much of that type of forest we have and approximately where it is located.

In many areas of nontimber resources the research necessary to associate animal or human behavioral patterns to physical attributes of the forest is the limiting factor in multiresource analysis. If we know what consumers or users of the forest resource want, we can tell them if we have it, how much we have, and where it is. In all future inventories, we see a clear need to define data in a multiresource rather than a functional framework. We are not resource managers, but we are mandated to provide useful multiresource management information. We need user assistance in determining what is useful management information.

SUMMARY

I have only glossed over some of what we think will significantly affect future resource inventories. Problems in the future will be numerous, and they may not be easily solved. We are embarking upon a new era in resource inventories with a great deal of new technology as well as optimism. Field data collected in the future will be more multiresource oriented, with more emphasis placed on remotely sensed data, data from other sources, and synthesized data such as that produced by growth simulation. The days of the field inventory are not over, but the economics and technology of the future must shift a greater share of the resource inventory burden to new and more sophisticated techniques.

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CONFERENCE WRAP-UP

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Forest survey has a long tradition of importance in this country as a basis for forest policy and planning. Several factors contribute to this being even more so today. As competition for our forest resources has intensified between uses and within uses, their values have become more evident. As a result, planning and the making of decisions regarding use and management of these resources have become more dependent on the availability and timeliness of good information. Mandated national and state level assessments of forest resources also add new dimensions to information needs. We see an increase in the array of interests desiring use of the forest. This results in the need for information of diverse forms and with high degrees of precision not previously required. All of these factors have contributed to increased demands for inventory information.

The professional forestry community in Minnesota and those with a vested interest in the actions of that community are represented at these conferences this week. It is beneficial to have the kind of open discussion and presentations on the Minnesota Forest Resource Inventory that have been evident today. They provide an opportunity for both an improved understanding by the users of this inventory information and as a means to communicate users concerns and needs to those responsible for the planning, conduct and reporting of such inventories.

During these conferences, we have heard an overview of forest inventory responsibilities authorized by Congress and carried out by the Forest Service. This explanation helped us put Minnesota in perspective relative to the national and regional purposes such inventories serve. We were informed that the goal of a 10-year inventory cycle has not yet been achieved largely because of funding limitations.

A report on the Lake States forest resource trends was presented. With 38% of the area of the three states classified as commercial forest land, the similarities in forest types and conditions across Michigan, Wisconsin, and Minnesota are important to the common populations these forests serve and to the common markets they presently and potentially impact. The 25% state, county, and municipal forest land ownership across this region is unique and provides a basis for more locally determined options for the forest resource than exists elsewhere.

We next turned to the Minnesota inventory itself and heard of the procedures used in the conduct of this inventory. Field sampling involved 8,547 ground plots measured between 1974 and 1978. State funding provided for a tripling of sampling intensity resulting in improved precision for estimates. The Minnesota timber utilization results for 1977 and the changes that have occurred in forest resource data resulting from this 1977 inventory were examined. Some highlights of these findings are as follows:

- An 11% decline in commercial forest land acreage from 1962 to 1977 resulted from a 1.7 million acre loss primarily from reservation for recreational use, urban encroachment, and conversion to agricultural use.
- Growing-stock volume showed a 21% increase over this same period.

The balance of the program was devoted to a discussion by representatives of the various users groups regarding the needs the inventory data can and should fulfill from their viewpoint. Identified as important needs the inventory should meet were:

- Data for planning by public bodies in regional analyses, land use and statewide resource assessments.
- Data base for the private sector for orderly planning of operations as well as for the development of strategic long range plans.
- Use in research in helping to interpret inventory in applications to a wide array of problems.
- As a basis for analyzing and interpreting resource conflict issues and management options in seeking solutions that are environmentally sound.
- To measure progress in a forest system toward policy or management goals.

Users emphasized the importance of timeliness in reporting inventory data and in being able to obtain access to the data base for special analyses.

Finally, a brief period was devoted to the issue of future forest resource inventories and changes that may be likely in their conduct. Among developments under consideration are the application of Bayesian estimators, land use change analysis, management information systems, and forest growth simulation. The integration of other resource data needs was also noted as an imperative.

This then leads me to some general observations resulting from the presentations and discussions here and from experiences as a user and observer of inventory information over time. First, the statewide forest resource inventories to which we are addressing ourselves are not and should not be considered as the source for all of our inventory data needs in forestry. The basic purpose of the statewide inventory is to provide information useful at a broad-based policy and program assessment level. This is essential to fulfilling the Congressional mandates as set forth in the legislation of 1928, 1974, and 1978. Accordingly, the statewide inventory data is not site-specific. That is, it does not provide site-specific answers for resource management decisions. In addition, the inventory fundamentally provides biological and physical resource information. Only in a very broad sense do economic criteria enter into the definitions that form the basis for what is measured and reported. As a result, other approaches are needed or special analyses must be made to provide location and economic oriented answers.

Second, there are diverse views on the scope, intensity, timing, and design needs for statewide forest inventories. Inventory data can be helpful to those who must make decisions regarding our forest resources. The issues and objectives for which inventory data are necessary to guide decisions in the public and private sectors vary. Thus, to some extent the inventory designs, techniques, standards, and definitions will vary in seeking to achieve efficiency for any one of the different needs. A statewide forest inventory such as we have been discussing can be only a compromise when designed to simultaneously serve several different sets of users. As a result, some users' expectations may significantly exceed what is deliverable or what is mandated as the principal focus of future inventories.

Third, it is still troubling to me that definitions and standards used to define measurements often play a subtle but significant role in impacting findings of a statewide inventory. Inclusion or exclusion for measurement in the inventory is automatic once such dimensions are established. Fourth, care in interpretation and analysis of inventory data is an important responsibility of anyone who makes public use of these data. Limitations of the data and the sampling precision for estimates sometimes are either overlooked or not understood. Fifth, efforts need to be directed more intensively toward incorporating other forest resource aspects into the inventory process. Finally, as important as today's discussion has been in informing those in attendance of the recent Minnesota forest inventory methods and results, we need to give additional effort to effectively reach the media and the broader publics who should have a better understanding of this information and the issues it addresses. Timely communication is a key unresolved need.

In summary, there have been significant advances in statistical and inventorying techniques. We are all conscious of the need for more efficient means of achieving our data needs for both policy and program assessment and for resource planning and management purposes. Adapting new methods and concepts which have been proven to statewide inventories seems to be an essential consideration in achieving such ends. Reviewing the roles and relationships between federal, state, and local governmental units and between the private sector to ensure that a planned and coordinated inventory effort on a statewide basis supplements and complements existing and ongoing inventory efforts by individual forest resource owners and organizations is another avenue for such gains. As inventory needs increase for uses and forest resources other than timber, added responsibilities and complexities will be assumed by the inventory process.

It is not too early for us to be thinking of the fifth statewide forest resource inventory in Minnesota, even while the fourth inventory is still not finalized. An adequate, comprehensive, cost effective, and acceptable forest inventory, while elusive, is the goal we can and should continue to seek. These conferences serve a useful end toward that purpose when appropriate follow-up is taken based on the presentations and discussions.

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1981. Proceedings of 1980 Minnesota Forest Resource Inventory Conferences. U.S. Department of Agriculture Forest Service, General Technical Report NC-64, 121 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Contains 16 papers presented at the 1980 Minnesota Forest Resource Inventory Conferences.

KEY WORDS: sampling plan, techniques, Lake States, timber output, volume, growth, data utilization.

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FOODS

of white-tailed deer in the Upper Great Lakes Region — a review

Lynn L. Rogers, Jack J. Mooty, and Deanna Dawson

orth Central Forest Experiment Station
orest Service, U.S. Department of Agriculture

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FOODS OF WHITE-TAILED DEER IN THE UPPER GREAT LAKES REGION—A REVIEW

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St. Paul, Minnesota

This report summarizes available information on the food habits of white-tailed deer *(Odocoileus virginianus)* in the northern forests of Minnesota, Wisconsin, and Michigan (fig. 1). This area, referred to here as the Upper Great Lakes Region (UGLR), is near the northern edge of the white-tail's present range (Taylor 1956).

Deer were not abundant in the mature, pine-dominated, "virgin" forests of the UGLR. However, the young hardwood forests created by large-scale logging and extensive forest fires allowed deer to expand their range northward (Swift 1946, Stenlund 1958, Erickson *et al.* 1961). Today, deer are important both aesthetically and economically in the UGLR. They are viewed and photographed as an important adjunct to the Region's tourist industry, and hunters spend over 200 million dollars a year on deer hunting (USDI 1977). Deer are also the main prey of the timber wolf *(Canis lupus)* in the UGLR. This Region has the only sizable population of wolves in the contiguous United States (Mech and Karns 1977).

The young forest that brought deer to the UGLR is now reaching maturity, and deer populations are declining (Byelich 1965, Stone 1966, Mooty 1971, Mech and Karns 1977). State governments in this Region are now spending nearly 2 million dollars a year on deer habitat improvement. However, optimal habitat management is difficult because the year-round food habits of deer in the UGLR have not been documented thoroughly. Study of growing-season food habits was begun only recently (Kohn and Mooty 1971, McCaffery *et al.* 1974, Mooty 1976, Bauer 1977). This review emphasizes the need for further information and is a step toward disseminating available information on deer food habits.

Research methods to obtain information on food habits of deer in the UGLR have included analyzing stomach contents, examining feeding sites, and observing tame deer on a leash. None of these methods gives a complete picture of food habits, and each has a different bias as will be discussed below. However, each method gives an approximation of the diet. Results of studies conducted in seven areas of the UGLR during 1936-1976 are presented in tables 1-12 (Appendix). Differences in reported diets reflect local differences in vegetation and differences in methods of study. Omitted from the tables are results of seven studies (Hammerstrom and Blake 1939, Swift 1946, Dahlberg and Guettinger 1956, Krefting and Hansen 1963, Orke 1966, McCaffery and Kohn 1971, and Hennings 1977) that did not permit percentage

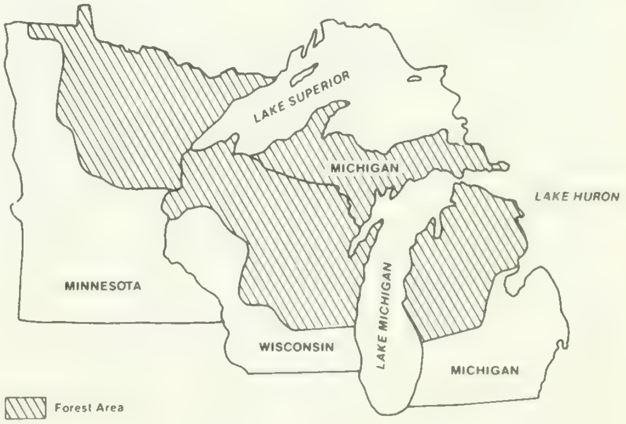

Figure 1.—*Northern forest area of the midwestern United States.*

breakdowns of diet or presentation by month. However, common and scientific names of foods mentioned in those studies are included in Appendix II which lists reported deer foods in the UGLR.

SEASONAL FOODS OF DEER IN THE UPPER GREAT LAKES REGION

Foods of deer can be categorized into such groups as woody browse, conifer needles, evergreen forbs, nonevergreen forbs, deciduous leaves, fruit, fungi, etc. Use of these groups by deer follows a seasonal trend throughout the UGLR despite local differences in vegetation.

In winter, woody browse usually is the main food available, and it forms the bulk of the diet (tables 1-4, 11-12). This food is low in nutrient quality and digestibility, and deer lose weight on it even when it is available in unlimited quantities (Ullrey *et al.* 1964, 1967, 1968, Verme and Ullrey 1972, Grigal *et al.* 1979). A prolonged diet of woody browse causes malnutrition and starvation (Mautz 1978), both of which are common in the UGLR in late winter (Bartlett 1938, Erickson *et al.* 1961, Stenlund 1970 Karns 1980).

Although cedar is a preferred winter food (Dahlberg and Guettinger 1956), needles of balsam fir, spruce, and pine apparently make an even poorer diet than most woody browse species. These needles comprised 58 to 60 percent of the rumen contents of starved deer autopsied in late winter during population highs of past decades (Aldous and Smith 1938, Dahlberg and Guettinger 1956). However, these needles made up only a small portion of the winter diet of healthier deer studied more recently (tables 1-3). Among the latter deer, the greatest use of balsam fir, pine, and spruce needles was by deer that eventually were killed by wolves. Sixteen percent of the stomach contents of 32 wolf-killed deer were needles of these species (Wetzel 1972).

After the rigors of a northern winter and a nutritionally marginal diet, fat reserves are depleted and deer become nutritionally stressed (Verme 1969, Mautz 1978, Karns 1980). In early spring, metabolic rates increase, does are in the last months of pregnancy, and a high quality diet is essential to both survival and reproductive success (Julander and Robinette 1950, Longhurst *et al.* 1952, Verme 1963, 1969, Silver *et al.* 1969). As snow melts on south-facing slopes and around the bases of trees in the uplands, deer begin supplementing their browse diets with leaves of small plants that remain green overwinter: bunchberry, wintergreen, strawberry, and barren strawberry (McCaffery and Kohn 1971). As spring progresses, new green grass, emerging forbs, and new leaves of trees and shrubs become available. Woody twigs and evergreen forbs are forsaken, and new green growth forms over 90 percent of the diet (table 4 and 5) (Pierce 1975). This vegetation is both nutritious and easily digestible (Verme and Ullrey 1972). At this time, deer frequently feed in treeless areas such as old fields, roadsides, and powerline rights-of-way which "green up" earlier than the surrounding forests (McCaffery and Creed 1969).

In late spring and early summer, deer, like moose *(Alces alces)*, are sometimes observed eating aquatic vegetation. Hennings (1977) observed deer in northeastern Minnesota selectively eating (in decreasing order of use) burreeds, filamentous algae, ribbonleaf pondweed, water horsetail, arrowhead, sedges, marsh cinquefoil, white pond lily, yellow pond lily, purple watershield, and St. John's-wort. Water milfoil and wild rice also have been reported as deer foods in the UGLR (Dahlberg and Guettinger 1956, Irwin 1974). Aquatic vegetation is fairly nutritious (Linn *et al.* 1973) and may be important in supplying annual requirements of sodium and other nutrients (Botkin *et al.* 1973, Jordan *et al.* 1974, Hanson and Jones 1977). Aquatic feeding reaches its peak during periods of reduced water levels in early summer (Townsend and Smith 1933, Behrend 1966, Skinner and Telfer 1974, Hennings 1977). The portion of the diet that aquatic vegetation comprises during periods of peak use is unknown but is probably low (Hennings 1977, Joyal and Scherrer 1978).

In summer, deer eat the leaves of nonevergreen terrestrial plants, mushrooms, and fruit (Kohn and Mooty 1971, McCaffery *et al.* 1974). Aspen forests, especially poorly stocked stands or those under 25 years of age, are important summer habitats (McCaffery and Creed 1969, Mooty 1971, McCaffery 1976, Bauer 1977, Gullion 1977). Leaves from aspen suckers less than one year old are a preferred food (McCaffery 1976). In northern Wisconsin, where first-year aspen suckers are abundant due to frequent clear-cutting of aspen forests, aspen leaves form a larger portion of the summer diet than does any other item (McCaffery *et al.* 1974). Leaves from older aspen are less preferred, however[1]. Consequently, in northern Minnesota where aspen clearcutting is less frequent aspen leaves form a smaller part of the summer diet (Kohn 1970, Pierce 1975). Leaves other than those of aspen also are important foods in aspen stands. Vegetation studies in Minnesota (Ohmann and Ream 1971), Wisconsin (McCaffery 1976), and Michigan (Bauer 1977) showed that principal summer deer foods such as maple, birch, willow, juneberry, hazel, cherry, honeysuckle, bush-honeysuckle, rose, large-leaf aster, and strawberry are prevalent in aspen stands.

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[1] *Personal communication with L. Verme, 1980.*

In the fall, nonevergreen leaves become increasingly scarce with the exception of large-leaf aster which persists in frost-sheltered stands into late fall. When nonevergreen leaves and other summer foods become scarce, deer turn to grasses, sedges, and evergreen forbs until these become covered by snow (tables 10 and 11). Then deer once again begin eating dormant woody browse which dominates the diet until the snow melts and the above cycle is repeated.

The seasonal feeding pattern indicates that deer generally prefer young nonevergreen leaves but will eat (in decreasing order of preference) mature nonevergreen leaves, evergreen forbs, cedar leaves, deciduous woody browse, and conifer needles. Preferred foods also may include arboreal fruticose lichens, acorns, fruit, and certain fungi according to studies conducted in other regions (Cushwa *et al.* 1970, Harlow and Hooper 1972, Skinner and Telfer 1974, Crawford *et al.* 1975). Additional study is needed to assess the importance of these foods in the UGLR.

Diversity apparently is important in the deer diet (Verme and Ullrey 1972). Dahlberg and Guettinger (1956) found that captive wintering deer maintained weight better on a variety of second-choice woody browse species than they did on a diet of straight cedar, a first-choice winter food. Miguelle and Jordan (1980) found that captive moose chose a diverse summer diet even when moutain-ash, a highly preferred food, was made available *ad libitum*. Jordan (1967) found deer preference for a species to be highest where that species was scarcest.

Perhaps one of the reasons ruminants choose a diverse diet is to avoid ingesting too much of any one of the many plant compounds that inhibit digestion (Nagy *et al.* 1964, Longhurst *et al.* 1968, Levin 1976). Deer have long been known to select the most nutritious forage available (Swift 1948, Weir and Torell 1959), and it now is apparent deer also detect and avoid compounds that inhibit the action of rumen micro-organisms (Nagy *et al.* 1964, Longhurst *et al.* 1968, Nagy and Regelin 1977). These secondary compounds, as they are called, have little or no impact on rumen micro-organisms at low concentrations (Nagy and Regelin 1977), but at higher concentrations, their inhibitory action accelerates (Nagy and Tengerdy 1968). A wide variety of secondary compounds are found in plants, with the amount and kind varying with species, subspecies, phenology, and site factors (Nagy and Regelin 1977). The palatability of plants decreases as concentrations of certain secondary compounds increase (Nagy and Regelin 1977).

A diverse diet may also benefit deer in another way. Eating certain plants may aid in the digestion of others. For example, some plants are too low in nitrogen, phosphorus, magnesium, or sulfur for adequate rumen digestion, but these plants may be utilized if they are combined with others that provide the deficient elements (Church 1977:138, Hanson and Jones 1977:254, 256).

PROBLEMS OF DEER IN NORTHERN FORESTED VERSUS SOUTHERN AGRICULTURAL DEER RANGES IN THE GREAT LAKES REGION

Deer at the northern edge of their range are limited in number mainly by problems of overwinter mortality and nutrition-related reproductive failures. These problems are eased by improvements in the quantity and quality of year-round food supply such as occur after extensive logging and burning (Erickson *et al.* 1961). However, problems increase in years when access to food patches is restricted by unusually deep or long-lasting snow (Moen 1976, 1978, Nelson and Mech 1980). Deer on the George Reserve in southern Michigan seldom dig through more than 3 inches (7.5 cm) of snow to reach food (Coblentz 1970) and deer in northcentral Minnesota have not been observed to dig through more than 12 inches (30 cm) of snow (Mooty and Rogers, personal observations). Travel becomes difficult when deer sink beyond their chests (about 20 inches (50 cm)) (Formozov 1946, Edwards 1956, Gilbert *et al.* 1970). Snow in the northern forests of Minnesota, Wisconsin, and Michigan becomes more than 20 inches deep nearly every winter (Environmental Science Services Administration 1968), burying low-growing plants beyond reach and hampering travel to the extent that even woody browse becomes difficult to obtain in quantity. By comparison, snow in the southern portions of these States usually is not as deep or long-lasting.

Studies in agricultural areas in Minnesota showed that snow-free patches enable deer to eat nonwoody foods longer than is usual in the UGLR (Moen 1966). The higher nutritional plane in these agricultural areas helps deer to withstand cold weather (Moen 1966). They spend much of their active and resting time near their food supplies in open fields and are not as likely to use heavy cover in winter as are deer farther north (Verme 1965, Moen 1966, Wetzel 1972). Deer in agricultural areas also show faster growth rates and higher reproductive rates than those in the forested north. Yearling bucks in southern Minnesota average 130 pounds (59 kg) field-dressed, while those in northeastern Minnesota average only 106 pounds (48 kg).[2] Between 29 and 52 percent of female fawns in southern Minnesota, Wisconsin, and Michigan become pregnant compared with only 3 to 11 percent in the northern portions of those states (Verme and Ullrey 1972, Harder 1980).

Deer in agricultural areas are able to achieve very high densities where hunting and other human-related mortality factors are controlled. A confined herd at the Twin Cities Army Ammunition Plant (TCAAP) achieved a density of 200 deer per square mile ($77/km^2$)[3], which is several times higher than densities recorded anywhere in the UGLR (Olson 1938, Erickson *et al.* 1961). Deer at the TCAAP usually survived overwinter by digging through shallow snow for herbaceous material[3]. In years when access to herbaceous material was prevented by an ice crust, fawns starved[3]. Herbaceous material is seldom available during winter in northern Minnesota forests.

Deer habitat in northern Lake and Cook Counties, in the northeastern corner of Minnesota, is deteriorating due to succession of aspen forest to balsam fir and spruce (Erickson *et al.* 1961, Urich 1973, Mech and Karns 1977). Nevertheless, the area still appears capable, from a food standpoint, of supporting at least 10 deer per square mile ($4/km^2$)[3]. However, during the late 1960s and early 1970s, a series of winters with unusually deep or long-lasting snow caused starvation and reproductive failure among those deer and made escape from timber wolves more difficult (Mech and Karns 1977). These natural factors, together with hunting by man, caused a severe decline in the deer population during the early 1970s (Mech and Karns 1977). Deer numbers fell to fewer than two per square mile (l/km^2) (Floyd *et al.* 1979) in some areas that formerly had been among the best deer hunting areas in the state (Olson 1938). Deer numbers declined to some extent throughout th UGLR (Mech and Karns 1977), but more recentl deer numbers over much of the UGLR have recovere considerably due to a return to more normal winter and tighter restrictions on deer hunting (Mech an Karns 1977, [4]). However, in northeastern Minnesot where losses to timber wolves are high (Mech an Karns 1977), no increase in deer numbers was d tected through 1978 (Floyd *et al.* 1979).

RESEARCH NEEDS IN THE UPPER GREAT LAKES REGION

Additional information is needed on deer diets i the snowfree seasons. Most previous studies in th UGLR were conducted in winter because it is the that food is scarcest and starvation greatest. However, it is now known that deer in the UGLR ar "semi-hibernators"; in winter, their metabolic rate decrease, they are less active, and they require les food (Silver *et al.* 1969, Thompson *et al.* 1973, Moe 1978). Studies of captive deer in northern Michiga showed some deer can survive overwinter even i they have no food for several weeks (Ozoga an Verme 1970). It is now apparent that overwinte survival depends not only on winter conditions but o the energy reserves deer accumulate before winte begins (Mautz 1978).

Knowledge of spring diet might prove useful t managers because the spring diet of pregnant does i especially crucial to the survival of their fawn (Verme 1962). Studies of captive deer showed tha fawn mortality was less than 33 percent when mothers that were undernourished in winter were well nourished in spring. However, when mothers wer undernourished in both winter and spring, faw mortality rose to 90 percent (Verme 1962). Growth c fawns depends largely on summer and fall nutritio and the fall weight of female fawns largel determines whether or not the fawns will bree (Harder 1980).

Information on diet during the snowfree months i difficult to obtain because present techniques are nc well suited for determining diet during that perioc One of the most common techniques, examinin feeding sites, depends upon deer leaving part of eac food plant behind so observers can see that some ha been eaten. This is a suitable method for approximating use of woody browse and large herbaceous plants. However, any feeding on small plants that are nipped off close to the ground, and any feeding on items that deer eat whole (mushrooms, berries, acorns, nuts, dried leaves, and lichens) is difficult to detect by this method. Moreover, unless radio-collared deer are used, feeding sites are difficult to find in the forest, so those examined tend to be in open or muddy areas where deer or their tracks are more visible (Peek 1975). According to Wallmo *et al.* (1973), inability to distribute the feeding site sample in proper relation to the distribution of deer feeding leads to underestimation of use of shrubs and forbs and overestimation of use of grasses. Aquatic feeding is missed entirely. Other problems with this method are determining how much of each species was eaten and whether browsing occurred days or months before the examinations (Peek 1975).

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[2] *Unpublished data by Ludwig and Karns on file.*
[3] *Personal communication with Karns, 1978.*

[4] *Personal comunication with Wm. Creed, 1980.*

Rumen analyses also are fraught with problems. Usually only a small portion of the rumen material is identifiable, with the identifiable items often being the least digestible ones (Bergerud and Russell 1964). Moreover, rumen contents usually are collected from deer killed along roads or in large open areas. Consequently, results are biased toward roadside grasses and other foods that grow in the open. In areas of low deer density, obtaining adequate samples of rumens in all seasons is another major difficulty.

Recently, observations of tame, harnessed deer have been used to determine summer food habits. Where comparisons have been made, food selections by tame deer did not differ from those of wild deer in similar habitats (Healy 1967, Longhurst *et al.* 1968, Wallmo and Neff 1970). However, in all studies using tame white-tailed deer, the researcher selected the feeding habitat. None of the available methods can be used to determine seasonal changes in amounts consumed per day.

Clearly, there is a need to develop improved techniques for determining food habits—especially for the snowfree months. An observation by Watts (1964) that an escaped tame deer remained tame after 2 weeks of freedom suggests that harnesses are unnecessary and that attempts should be made to study tame radio-marked deer living unfettered and full time on natural ranges. Such deer could become fully familiar with the habitats and foods available in their home ranges and could select them without being hindered by researchers. Feeding data obtained by observing these deer would not be biased in the ways inherent in the other methods mentioned. Around-the-clock observations of these deer in all seasons would reveal any day-night differences in habitat use and any seasonal differences in daily consumption rates. The validity of this approach might be tested, in part, by determining whether the tame deer survive, reproduce, and raise young as successfully as wild ones under conditions of severe winters and predation by timber wolves. The number of deer required for such study would depend upon the extent to which individuals differed from one another in their food preferences.

Land managers need more information on year-round diet in order to determine which timber management practices produce the best deer habitats. Information on year-round diet also is needed to determine the effects of such natural factors as fire, drought, plant disease, and defoliating insects on deer habitat. These factors can change both the kinds and the nutritional values of the plants available to deer (McEwen and Dietz 1965, Halls and Epps 1969, Urich 1973, Lyon *et al.* 1978, Ohmann and Grigal 1979). Information on year-round diet will lead to a better understanding of the relations between deer and their habitat and will enable land managers to maximize the benefits from deer habitat management funds.

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APPENDIX

Table 1.—*Plants eaten by white-tailed deer in northern Minnesota in January*

(In estimated percents of the diet)[1]

	Feeding sites			Rumens (northeast)
	North-central	Northeast		
	1971-1974[2]	1971[3]	1972[4]	1971[3]
Beaked hazel	37	30	35	16
Mountain maple	10	29	25	3
Dogwood	1	15	10	6
Juneberry	12	6	14	2
Arboreal lichens			14	
Balsam fir	<1	<1	13	
Green alder	8	1	1	8
Blueberry	8			
Red maple		4	6	
Quaking aspen	2	4	1	
Paper birch	4	1	1	
Grasses	<1			4
Goldthread				4
Cherry	2	1	3	3
Labrador tea	3	2		1
White cedar		<1	3	<1
White pine	2			1
Black spruce				2
Wintergreen	2			
Willow	1	1	1	<1
Speckled alder		<1	<1	1
Bush-honeysuckle	<1	1		
Arrowwood		1	<1	
Red oak		<1	<1	
Honeysuckle		<1	<1	
Jack pine	<1			
Unidentified leaves				6
Unidentified twigs				15
Number examined	9	26	16	8
Number of bites	2,064	24,797	7,027	

[1] Not included in tables 1-3 and 12 are 22 taxa whose use by deer did not exceed 1.5 percent of the diet in any study in any month during December-March. These taxa include clubmoss, bracken fern, mosses, large-leaf aster, black medic, strawberry, marsh marigold, goldenrod, thistles, trailing arbutus, red raspberry, gooseberry, rose, red elderberry, leatherleaf, sweet gale, swamp birch, sumac, mountain-ash, black ash, balsam poplar, and red pine.

[2] Mooty (unpublished). Data for December-March were obtained by examining 43 feeding sites in Itasca County, north-central Minnesota, during 1971-1974. For a summary of these data by 2-month intervals, see Mooty (1976). Deer density during the study was 4 to 8 deer per square kilometer and declining, according to annual spring pellet counts conducted by the Minnesota Department of Natural Resources.

[3] From Wetzel (1972). Data for December-March were obtained by examining 82 feeding sites and 32 wolf-killed rumens in St. Louis and Lake Counties in northeastern Minnesota during 1968-1971. Deer density was 4 to 6 deer per square kilometer and declining (P. D. Karns, 1979, personal communication; Mech and Karns 1977; Rogers *et al.* 1980).

[4] From Wambaugh (1973). Data for January-March were obtained by examining 50 feeding sites in 1972 in the same area that had been studied by Wetzel (above).

Table 2.—*Plants eaten by white-tailed deer in northern Minnesota in February*

(In estimated percents of the diet)[1]

	Feeding sites			**Rumens (northeast)**
	North-central	**Northeast**		
	1972[2]	**1971[3]**	**1972[4]**	**1971[3]**
White cedar		8		52
Beaked hazel	35	33	48	4
Mountain maple		29	37	
Labrador tea	14	1		
White pine	3		12	
Blueberry	10			
Jack pine	9			8
Juneberry	8	2	4	1
Dogwood		8	1	2
Willow	6	1	<1	
Speckled alder	5	2	<1	5
Balsam fir		1		5
Red maple		5	2	
Arboreal lichens				4
Honeysuckle	3		<1	
Quaking aspen		2	2	
Arrowwood		2	<1	
Green alder		2	<1	<1
Hawthorn	2			
American hazel	2			
Cherry	1	1	1	<1
Paper birch	<1	1	<1	1
Wintergreen	1			
Sweetfern	1			
Red oak		<1	<1	
Bush-honeysuckle		<1		
Black spruce				<1
Grasses, sedges				<1
Unidentified leaves				1
Unidentified twigs				4
Number examined	7	37	20	15
Number of bites	1,458	35,200	12,616	

[1] Not included in tables 1-3 and 12 are 22 taxa whose use by deer did not exceed 1.5 percent of the diet in any study in any month during December-March. These taxa include clubmoss, bracken fern, mosses, large-leaf aster, black medic, strawberry, marsh marigold, goldenrod, thistles, trailing arbutus, red raspberry, gooseberry, rose, red elderberry, leatherleaf, sweet gale, swamp birch, sumac, mountain-ash, black ash, balsam poplar, and red pine.

[2] Mooty (unpublished). Data for December-March were obtained by examining 43 feeding sites in Itasca County, north-central Minnesota, during 1971-1974. For a summary of these data by 2-month intervals, see Mooty (1976). Deer density during the study was 4 to 8 deer per square kilometer and declining, according to annual spring pellet counts conducted by the Minnesota Department of Natural Resources.

[3] From Wetzel (1972). Data for December-March were obtained by examining 82 feeding sites and 32 wolf-killed rumens in St. Louis and Lake Counties in northeastern Minnesota during 1968-1971. Deer density was 4 to 6 deer per square kilometer and declining (P. D. Karns, 1979, personal communication; Mech and Karns 1977; Rogers *et al.* 1980).

[4] From Wambaugh (1973). Data for January-March were obtained by examining 50 feeding sites in the same area that had been studied by Wetzel (above).

Table 3.—*Plants eaten by white-tailed deer in northern Minnesota in March*

(In estimated percents of the diet)[1]

	Feeding sites			Rumens (northeast)	
	North-central	Northeast			
	1972[2]	1971[3]	1972[4]	1971[3]	1937[5]
Beaked hazel	52	44	51	4	
Balsam fir	1	<1		5	43
White cedar		26		35	3
Jack pine	5			17	
Mountain maple		12	16		
Pine					14
Juneberry	8	2	11		
Dogwood	3	1	4	9	<1
Paper birch	5	1	<1	1	5
Green alder	4	5	2		<1
Arrowwood		<1	<1		5
Arboreal lichens				5	
Red maple	<1	2	4		<1
Willow	1	1	<1	1	4
Cherry	1	1	<1	3	<1
Speckled alder		1	3		<1
Black spruce				1	3
Red oak	<1	<1	3		<1
Grasses, sedges				<1	3
Labrador tea		<1			3
Honeysuckle	3				
Quaking aspen	2	1	2		
White pine	2			1	
Blueberry	2				
Large-toothed aspen	1				
Bush-honeysuckle		<1			
Wintergreen	<1				
Bunchberry	<1				
Unidentified leaves				1	
Unidentified twigs				8	
Other material				7	
Number examined	15	15	14	4	51
Number of bites	3,700	19,666	6,228		

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[1] Not included in tables 1-3 and 12 are 22 taxa whose use by deer did not exceed 1.5 percent of the diet in any study in any month during December-March. The taxa include clubmoss, bracken fern, mosses, large-leaf aster, black medic, strawberry, marsh marigold, goldenrod, thistles, trailing arbutus, red raspberr gooseberry, rose, red elderberry, leatherleaf, sweet gale, swamp birch, sumac, mountain-ash, black ash, balsam poplar, and red pine.

[2] Mooty (unpublished). Data for December-March were obtained by examining 43 feeding sites in Itasca County, north-central Minnesota, during 1971-1974. F a summary of these data by 2-month intervals, see Mooty (1976). Deer density during the study was 4 to 8 deer per square kilometer and declining, according annual spring pellet counts conducted by the Minnesota Department of Natural Resources.

[3] From Wetzel (1972). Data for December-March were obtained by examining 82 feeding sites and 32 wolf-killed rumens in St. Louis and Lake Counties northeastern Minnesota during 1968-1971. Deer density was 4 to 6 deer per square kilometer and declining (P. D. Karns, 1979, personal communication; Mech a Karns 1977; Rogers *et al.* 1980).

[4] From Wambaugh (1973). Data for January-March were obtained by examining 50 feeding sites in the same area that had been studied by Wetzel (above

[5] From Aldous and Smith (1938). Data were obtained in northeastern Minnesota by examining 51 rumens from deer that had died of starvation, predatio sickness, exposure, or having been struck by vehicles late in the winter of 1936-1937. Deer density was 4 to 8 per square kilometer according to deer driv conducted by the Civilian Conservation Corps in the Superior National Forest in 1936.

Table 4.—*Plants eaten by white-tailed deer in north-central Minnesota in April of 1970 and 1971*

(In estimated percents of diet)[1]

	Feeding sites	Rumens
White-cedar		48
Beaked hazel	21	2
Green alder and speckled alder	2	18
Bush-honeysuckle	15	
Grasses	14	
Red osier dogwood	10	
Late low blueberry	9	
Juneberry	6	
Goldenrod (dead)	5	
Sedges	5	
Black ash	3	
Honeysuckle	3	
Marsh marigold	3	
Lichens		2
Unidentified woody browse		30
Number of sites or rumens examined	11	5
Number of bites	1,833	

[1] From Pierce (1975). Data were obtained by examining 39 feeding sites and 3 rumens in Itasca County, north central Minnesota, during April-June 1970-1971. Five rumens from deer that starved in April in Itasca County were examined. Deer density was 4 to 8 per square kilometer and declining, according to annual spring pellet counts conducted by the Minnesota Department of Natural Resources. Items used in amounts less than two percent in April included twigs of paper birch, quaking aspen, and cherry and sprigs of jack pine and white pine. Bush-honeysuckle, grass, sedge, and marsh marigold were eaten mainly in late April after some snow had melted.

Table 5.—*Plants eaten by white-tailed deer in north-central Minnesota in May of 1970 and 1971*

(In estimated percents of diet)[1]

	Feeding sites	Rumens
Grasses	45	7
Sedges	17	
Willow	3	6
Goldenrod (dead)	5	
Marsh marigold	5	
Red osier dogwood	4	2
Wood anemone	4	
Bracken fern		4
Trailing arbutus		3
False lily-of-the-valley	3	
Rose	3	
Yellow bellwort	3	
Late low blueberry	3	
Large-leaf aster	2	
Clinton's lily	2	
Unidentified leaves		64
Unidentified forbs		13
Number of sites or rumens examined	16	3
Number of bites tallied	4,595	

[1] From Pierce (1975). For additional details of the study, see footnote to table 4. Items used by deer in amounts less than 2 percent in May include hazel, quaking aspen, and pyrola.

Table 6.—*Plants eaten by white-iailed deer in the northern Great Lakes Region in June*

(In estimated percents of the diet)[1]

	Feeding sites (Minnesota)		Rumens		Observation of tame deer (Michigan)	
	Forest[2]	**Burn**[3]	**Minnesota**[4]	**Wisconsin**[5]	**Aspen**[6]	**Clearcut**[6]
Aspen	1	16	6	29	21	37
Red maple and mountain maple	8	22	14	5	1	9
Bracken fern	13		<		19	7
Dogwood	1		18			
Beaked hazel	9	4			14	16
Bush-honeysuckle	1		16	5		
Strawberry	2		5	15	4	9
Wild sarsaparilla	14				<	
Lily family	2			12	3	<
Water milfoil		11				
Raspberry					8	5
Willow	8		1		4	<
Hawkweed			8		2	<
Honeysuckle	8					
Grasses and sedges	7	3	6	6	2	2
Chokecherry			1		7	6
Aster, mainly large-leafed aster	6		1		6	2
Paper birch	1	6	2			<
Sweet pea	5		5			
Yellow bellwort	4					
Goldenrod	3		2		3	<
Bunchberry	3				<	<
Juneberry	2		2			
Miscellaneous species		20				
Unidentified leaves			9			
Number of sites or rumens examined	12	6	3	24		
Number of bites	2,763	492				

[1] Plants whose use by deer did not reach 2 percent of the diet in any study in June were mushrooms, pyrola, bluebell, spreading dogbane, violet, goosefoot, bedstraw, common dandelion, yarrowm pearly everlasting, indian hemp, hedge bindweed, scarlet columbine, fireweed, thistle, late low blueberry, thimbleberry, currant, rose, arrowwood, black ash, bur oak, and white spruce.

[2] From Pierce (1975). For additional details of the study, see footnote to table 4.

[3] From Irwin (1974). Data were obtained by examining 52 feeding sites in the Little Sioux Burn area in St. Louis County, northeastern Minnesota during April-December 1973. Deer density was 4 to 6 per square kilometer (P. D. Karns, 1979, personal communication).

[4] From Kohn (1970). Data were obtained by examining 31 feeding sites and 9 rumens in Itasca County, north-central Minnesota, during June-August 1968-1969. Deer population data are as for Pierce (1975) (above). Kohn did not mention by name 11 browse and 20 forb taxa each of which accounted for no more than 2 percent of the diet in any month of study.

[5] From McCaffery *et al.* (1974). Data were obtained in northern Wisconsin during 1969-1970 by examining 76 rumens from road-killed deer (15 in April-May, 42 in June-September, 19 in October-November). Seventy genera, excluding genera of grasses, sedges, and mushrooms, were found in the 76 rumens, but 17 items accounted for 80 percent of the aggregate volumes for April-November. These 17 items were aspen leaves (16 percent), graminoids (1 percent), barren strawberry (7 percent), aster (5 percent), bush-honeysuckle (6 percent), strawberry (4 percent), cherry (4 percent), oak acorns (6 percent), wintergreen (3 percent) clover (4 percent), mushrooms (2 percent), maple leaves (2 percent), solomon's seal (2 percent), false lily-of-the-valley (2 percent), and bunchberry (2 percent). Approximately monthly break-downs are available for June only. Deer density was 6 to 8 per square kilometer and declining (Wm. F. Creed, 1978, personal communication).

[6] From Bauer (1977). Data were obtained by observation of 3 tame, harnessed deer in a 10-acre mature aspen stand and in an adjacent 10-acre 1-year-old aspen clearcut during June-August 1976 in Dickinson County in Michigan's Upper Peninsula. Deer density was 11 per square kilometer and declining (L. F. Verme, 1979, personal communication).

Table 7.—*Plants eaten by white-tailed deer in the northern Great Lakes Region in July*

(In estimated percent of the diet)[1]

	Feeding sites (Minnesota)		Rumens (Minnesota)	Observations of tame deer (Michigan)	
	Forest[7]	**Burn[3]**	**Forest[4]**	**Aspen[6]**	**Clearcut[6]**
Aspen	7	3	22	26	20
Beaked hazel	26			9	20
Strawberry	3		11	10	17
Red and mountain maple	10	5	16	8	13
Goldenrod	1	12	4	2	3
Choke and pin cherry	<1	12	4	3	2
Bracken fern	3		3	12	3
Asters, mainly large-leafed aster	9	10		3	5
Raspberry	1			10	6
Rough cinquefoil		10			
Willow	9			4	2
Juneberry	3	8	2		
Spotted jewelweed	3	8			
Bush-honeysuckle	<1	2	7		
Grasses and sedges	1		6	2	2
Violet	<1		5		
Paper birch	3	4	1		<1
Common geranium			4		
Water milfoil		4			
Fireweed	3				
Clover	2	2			
Hedge bindweed				2	2
False lily-of-the-valley	1			2	<1
Hawkweed				2	<1
Spreading dogbane	1		2		
Bicknell's geranium	2				
Mushrooms	<1		2		
Arrowwood	2				
Unidentified leaves			7		
Miscellaneous species		17			
Number of feeding sites or rumens examined	21	8	3		
Number of bites tallied	5,098	778			

[1] Plants whose use by deer did not reach 2 percent of the diet in August included Hawkweed, common dandelion, rough cinquefoil, pyrola, pearly everlasting, black snakeroot, meadow rue, indian hemp, bluebell, sweetfern, barren strawberry, arrowwood, thistle, bedstraw, mint, wild lettuce, hedge bindweed wild sarsaparilla, honeysuckle, green alder, and white spruce.

[3] From Irwin (1974). Data were obtained by examining 52 feeding sites in the Little Sioux Burn area in St. Louis County, northeastern Minnesota during April-December 1973. Deer density was 4 to 6 per square kilometer. (P. D. Karns, 1979, personal communication).

[4] From Kohn (1970). Data were obtained by examining 31 feeding sites and 9 rumens in Itasca County, north-central Minnesota, during June-August 1968-1969. Deer population data are as for Pierce (1975) (above). Kohn did not mention by name 11 browse and 20 forb taxa each of which accounted for not more than 2 percent of the diet in any month of study.

[6] From Bauer (1977). Data were obtained by observation of 3 tame, harnessed deer in a 10-acre mature aspen stand and in an adjacent 10-acre 1-year-old aspen clearcut during June-August 1976 in Dickinson County in Michigan's Upper Peninsula. Deer density was 11 per square kilometer and declining (L. F. Verme, 1979 personal communication).

[7] Mooty (unpublished). Data were obtained by examining feeding sites in Itasca County, north-central Minnesota during 1968-1971. For a summary of these data by 2-month intervals, see Mooty (1976). Some of the data used by Mooty were contributed by Kohn (1970) and Waddell (1973). Deer density was 4 to 8 per square kilometer and declining, according to annual spring pellet counts conducted by the Minnesota Department of Natural Resources.

Table 8.—*Plants eaten by white-tailed deer in the northern Great Lakes Region in August*

(In estimated percent of the diet)[1]

	Feeding sites (Minnesota)		Rumens	Observations of tame deer (Michigan)	
	Forest[7]	Burn[3]	(Minnesota)[4]	Aspen[6]	Clearcut[6]
Aspen	8		12	23	9
Beaked and american hazel	15	<2		15	23
Bush-honeysuckle	7	20	9		
Strawberry	1	<1		9	17
Mushrooms			17		
Choke and pin cherry	3	16	6	4	<1
Asters, mainly large-leafed aster	15	<2	6	13	2
Red and mountain maple	5	5	9	2	15
Raspberry and Blackberry	<1			13	4
Clover	4	11			
Paper birch	6	8	<1		1
Fireweed		8			
Willow	6	5	3	7	2
Spreading dogbane	6	1			
Spotted jewelweed	6				
Buckbean	5				
Wild sweet pea	3		4		
Grasses and sedges	1		3	1	2
Juneberry	1	<2	4		
Lillies, mainly Clinton's lily	3			2	<1
American Vetch	1		3		
Bristly Sarasparilla	<1	3			
Fringed bindweed		3			
Goldenrod	2		<1	2	2
Rose	1		2		
Bracken fern	1			2	<1
Dogwood	2		1		
Thimbleberry	2				
Violet	2				
Blueberry	2				
Basswood	2				
Unidentified leaves			14		
Miscellaneous plants		21			
Number of feeding sites or rumens examined	26	8	3		
Number of bites	7,964	570			

[1] Plants whose use by deer did not reach 2 percent of the diet in any study in August included Hawkweed, common dandelion, rough cinquefoil, pyrola, pearly everlasting, black snakeroot, meadow rue, indian hemp, bluebell, sweetfern, barren strawberry, arrowwood, thistle, bedstraw, mint, wild lettuce, hedge bindweed wild sarsaparilla, honeysuckle, green alder, and white spruce.

[3] From Irwin (1974). Data were obtained by examining 52 feeding sites in the Little Sioux Burn area in St. Louis County, northeastern Minnesota during April-December 1973. Deer density was 4 to 6 per square kilometer. (P. D. Karns, 1979, personal communication).

[4] From Kohn (1970). Data were obtained by examining 31 feeding sites and 9 rumens in Itasca County, north-central Minnesota, during June-August 1968-1969. Deer population data are as for Pierce (1975) (above). Kohn did not mention by name 11 browse and 20 forb taxa each of which accounted for not more than 2 percent of the diet in any month of study.

[6] From Bauer (1977). Data were obtained by observation of 3 tame, harnessed deer in a 10-acre mature aspen stand and in an adjacent 10-acre 1-year-old aspen clearcut during June-August 1976 in Dickinson County in Michigan's Upper Peninsula. Deer density was 11 per square kilometer and declining (L. F. Verme, 1979 personal communication).

[7] Mooty (unpublished). Data were obtained by examining feeding sites in Itasca County, north-central Minnesota during 1968-1971. For a summary of these data by 2-month intervals, see Mooty (1976). Some of the data used by Mooty were contributed by Kohn (1970) and Waddell (1973). Deer density was 4 to 8 per square kilometer and declining, according to annual spring pellet counts conducted by the Minnesota Department of Natural Resources.

Table 9.—*Plants eaten by white-tailed deer in northern Minnesota in September*

(In estimated percentages of the diet)[1]

	Forested feeding sites[8]	Burned feeding sites[3]
Bush-honeysuckle	24	36
Asters, mainly large-leafed aster	33	3
Pin cherry		20
Fringed bindweed		11
Clover	10	9
Mountain maple	9	4
Willow	6	2
Bristly sarsaparilla		6
Clinton's lily	3	<2
Goldenrod	3	
Bracken fern	3	
Red maple	2	<2
Rose	2	<2
Miscellaneous plants		9
Number of feeding sites	12	5
Number of bites tallied	2,932	490

[1] Plants whose use by deer did not reach 2 percent in either study in August included raspberry, blackberry, grass, sedge, bunchberry, strawberry, thistle, beaked hazel, American hazel, quaking aspen, and arrowwood.

[3] From Irwin (1974). Data were obtained by examining 52 feeding sites in the Little Sioux Burn area in St. Louis County, northeastern Minnesota during April-December 1973. Deer density was 4 to 6 per square kilometer (P. D. Karns, 1979 personal communication).

[8] From Waddell (1973). Data were obtained by examining 41 feeding sites during August-October 1970-1971 in Itasca County, north-central Minnesota. Waddell did not mention by name 56 plant taxa, each of which accounted for not more than 2 percent of the diet in any of the 3 months of study. Deer density was four to eight square kilometer according to census data collected by the Minnesota Department of Natural Resources.

Table 10.—*Plants eaten by white-tailed deer in northern Minnesota in October*

(In estimated percentages of the diet)[1]

	Forested feeding sites[8]	Burned feeding sites[3]
Red maple		49
Grasses and sedges	29	5
Bush-honeysuckle	13	
Beaked and american hazel	1	12
Clover	7	11
Aster, mainly large-leafed aster	11	
Bunchberry	8	2
Goldenrod	8	
Paper birch	1	7
Wintergreen	5	2
Quaking aspen	5	2
Jack pine		4
Juneberry		4
Raspberry and blackberry	2	2
Strawberry	2	2
Common thistle	2	
Hedge bindweed	2	
Miscellaneous plants		8
Number of feeding sites examined	13	6
Number of bites tallied	5,483	480

[1] Plants whose use by deer did not reach 2 percent of the diet in either study in October included rose, willow, alder, and fireweed.

[3] From Irwin (1974). Data were obtained by examining 52 feeding sites in the Little Sioux Burn area in St. Louis County, northeastern Minnesota during April-December 1973. Deer density was 4 to 4 per square kilometer (P. D. Karns, 1979, personal communication).

[8] From Waddell (1973). Data were obtained by examining 41 feeding sites during August-October 1970-1971 in Itasca County, north-central Minnesota. Waddell did not mention by name 56 plant taxa, each of which accounted for not more than 2 percent of the diet in any of the 3 months of study. Deer density was 4-8 per square kilometer according to census data collected by the Minnesota Department of Natural Resources.

Table 11.—*Plants eaten by white-tailed deer in the northern Great Lakes Region in November*

(In estimated percentages of the diet as determined from rumen analyses).

	Northeast Minnesota		**Northern Wisconsin**
	1967-1969[1]	**1936[2]**	**1943[3]**
Large-leaf aster	25		
Eastern hemlock		20	
Quaking aspen and balsam poplar	4	17	11
White-cedar		9	15
Balsam fir		13	12
Grasses	11	3	<2
Willow	1	11	
Birch	10	<2	
Bunchberry	8	2	<2
Red osier dogwood	8		
Pine (mainly jack pine)	1	7	7
Green and speckled alder	3	<1	5
Labrador tea		5	
Apple	5		
Bog laurel	4		
Currant or gooseberry	4		
Wintergreen			4
Beaked and American hazel	1	<1	3
Twinflower	3	<1	
Rose		3	
Maple		2	2
Mushrooms, lichens, and moss		2	<2
Common thistle	2		
Wood fern			2
Wild sweet pea	2		
Composite family		2	
Unidentified twigs	12	12	1
Number of rumens examined	14	21	387

[1] From Wetzel (1972). Data for November were obtained by examining 14 rumens from deer killed by hunters in St. Louis and Lake Counties in northeastern Minnesota during 1967-1969. Deer density was 4 to 6 per square kilometer (P. D. Karns, 1978, personal communication), and the population was declining (Mech and Karns 1977; Rogers *et al.* 1980). Wetzel omitted and did not name 25 items that he found only in trace amounts during the 3 years he analyzed rumens.

[2] From Aldous and Smith (1938). Data for November were obtained by examining 21 rumens from deer killed by hunters in northeastern Minnesota in 1936. Items which Aldous and Smith found to comprise less than 1 percent of the diet included black spruce, basswood, clubmoss, raspberry, juniper, goldenrod, clover, grape, grape fern, hardhack, ironwood, loosestrife, sheep sorrel, elm, cherry, and oak.

[3] From Dahlberg and Guettinger (1956). Data for November were obtained by examining 387 rumens from deer killed by hunters in northern Wisconsin in 1943. Fifty plant species, in addition to those listed in table 11, were listed by Dahlberg and Guettinger as contributing trace amounts to the diet.

Table 12.—*Plants eaten by white-tailed deer in northern Minnesota in December*

(In estimated percentages of the diet as determined through examination of feeding sites)[1]

	Forested feeding sites		Burned feeding sites
	Northeast[2]	North central[3]	Northeast[4]
Dogwood	44	16	
Red maple	10	<1	40
Sweetfern			23
Beaked and American hazel	13	22	
Jack pine		2	19
Mountain maple	15	<1	2
Blueberry		15	
Wintergreen		12	
Labrador tea		<1	9
Juneberry	7	6	2
Green alder		6	
Bunchberry		4	
Bush-honeysuckle	3	2	
Willow	<1	3	
Quaking aspen	2	<1	<2
Sedge		2	
Miscellaneous plants			5
Number of feeding sites examined	4	12	10
Number of bites tallied	2,112	1,861	782

[1] Plants whose use by deer did not reach 2 percent in any of the studies in December included thistles, trailing arbutus, clubmoss, strawberry, honeysuckle, red raspberry, balsam poplar, paper birch, cherry, staghorn sumac, rose, red oak, black ash, and white pine.

[2] From Wetzel (1972). For additional details of that study, see footnote 3 of table 1.

[3] Mooty (unpublished). For additional details of that study, see footnote 7, table 7.

[4] From Irwin (1974). For additional details of that study, see footnote 3, table 6.

COMMON AND SCIENTIFIC NAMES OF PLANTS EATEN BY DEER IN THE UPPER GREAT LAKES REGION

Common name	Scientific name	Season eaten[1]
TREES:		
American beech	*Fagus grandifolia*	
American elm	*Ulmus americana*	
American larch or tamarack	*Larix laricinia*	
Apple	*Pyrus* spp.	F
Ash	*Fraxinus* spp.	
Aspen	*Populus* spp.	Su, F, W
Balsam fir	*Abies balsamea*	F, W
Balsam poplar	*Populus balsamifera*	F
Basswood	*Tilia americana*	W

Birch	*Betula* spp.			F,	W
Bitternut hickory	*Carya cordiformis*				
Black ash	*Fraxinus nigra*				W
Black cherry	*Prunus serotina*				W
Black spruce	*Picea mariana*				
Blue beech	*Carpinus caroliniana*				
Box elder	*Acer negundo*				
Bur oak	*Quercus macrocarpa*				W
Butternut	*Juglans cinerea*				
Eastern hemlock	*Tsuga canadensis*			F	
Elm	*Ulmus* spp.				
Green ash	*Fraxinus pennsylvanica*				W
Hornbeam or Ironwood	*Ostrya virginiana*				
Jack pine	*Pinus banksiana*			F,	W
Large-toothed aspen	*Populus grandidentata*		Su,		W
Maple	*Acer* spp.		Su,		W
Mountain-ash	*Sorbus americana*				W
Oak	*Quercus* spp.		Su,		W
Paper birch	*Betula papyrifera*		Su,	F,	W
Pine	*Pinus* spp.			F,	W
Quaking aspen	*Populus tremuloides*		Su,	F	
Red maple	*Acer rubrum*		Su,	F,	W
Red oak	*Quercus rubra*				
Red pine	*Pinus resinosa*				
Silver maple	*Acer saccharinum*				
Sugar maple	*Acer saccarum*				
Swamp birch	*Betula pumila*				
White-cedar	*Thuja occidentalis*	Sp,		F,	W
White pine	*Pinus strobus*				W
White spruce	*Picea glauca*				
Wild crab	*Pyrus angustifolia*				
Yellow birch	*Betula lutea*				

SHRUBS AND VINES:

Alder	*Alnus* spp.	Sp,		F,	W
Alderleaf buckthorn	*Rhamnus alnifolia*				
Alternate-leaved dogwood	*Cornus alternifolia*				W
American hazel	*Corylus americana*		Su,	F,	
Arrowwood	*Viburnum* spp.				
Beaked hazel	*Corylus cornuta*	Sp,	Su,	F,	W
Bearberry	*Arctostaphylos uva-ursi*				
Blackberry and raspberry	*Rubus* spp.		Su		
Black-haw	*Viburnum lentago*				
Blueberry	*Vaccinium* spp.	Sp,			W
Bog birch	*Betula pumila*				
Bog laurel	*Kalmia polifolia*				
Bog rosemary	*Andromeda glaucophylla*				
Buffalo berry	*Sheperdia argentea*				
Bush-honeysuckle	*Diervilla lonicera*	Sp,	Su,	F	
Canadian fly honeysuckle	*Lonicera canadensis*				
Cherry	*Prunus* spp.		Su		
Chokeberry	*Pyrus melanocarpa*				W
Choke cherry	*Prunus virginiana*		Su		
Common elder	*Sambucus canadensis*				

Creeping snowberry	*Gaultheria hispidula*	
Currant	*Ribes* spp.	
Swamp currant	*Ribes lacustre*	
Dogwood	*Cornus* spp.	Sp, Su, W
Downy arrow-wood	*Viburnum rafinesquianum*	W
Eastern blackberry	*Rubus allegheniensis*	
Elderberry	*Sambucus* spp.	
Gooseberry	*Ribes* spp.	
Gray dogwood	*Cornus racemosa*	W
Greenbriar	*Smilax* spp.	
Green alder	*Alnus crispa*	Sp, W
Hairy honeysuckle	*Lonicera hirsuta*	
Hardhack	*Spiraea tomentosa*	
Hawthorn	*Crataegus* spp.	
Hazel	*Corylus* spp.	Sp, Su, F, W
Highbush blueberry	*Vaccinium corymbosum*	
Highbush cranberry	*Viburnum trilobum*	W
Honeysuckle	*Lonicera* spp.	Su
Juneberry	*Amelanchier* spp.	Sp, Su, W
Juniper	*Juniperus* spp.	
Labrador tea	*Ledum groenlandicum*	F, W
Late low blueberry	*Vaccinium angustifolium*	Sp
Leatherleaf	*Chamaedaphne calyculata*	
Leatherwood or moosewood	*Dirca palustris*	
Lilac	*Syringa vulgaris*	
Meadow rose	*Rosa blanda*	
Meadow sweet	*Spiraea latifolia, S. alba*	
Mountain-holly	*Nemopanthus mucronatus*	
Mountain maple	*Acer spicatum*	Su, W
New Jersey tea	*Ceanothus americanus*	
Ninebark	*Physocarpus opulifolius*	
Northern holly or winterberry	*Ilex verticillata*	
Northern yew	*Taxus canadensis*	
Pin cherry	*Prunus pennsylvanica*	Su
Pipsissewa	*Chimaphila umbellata*	
Poison Ivy	*Rhus radicans*	
Prairie willow	*Salix humilis*	
Prickly ash	*Xanthoxylum americanum*	
Raspberry	*Rubus strigosus*	Su
Red-berried elder	*Sambucus pubens*	
Red osier dogwood	*Cornus stolonifera*	Sp, Su, F, W
Red-panicle dogwood	*Cornus racemosa*	
Rose	*Rosa* spp.	
Round-leaved dogwood	*Cornus rugosa*	W
Small cranberry	*Vaccinium oxycoccus*	
Smooth climbing honeysuckle	*Lonicera dioica*	
Smooth sumac	*Rhus glabra*	
Snowberry	*Symphoricarpos albus*	
Speckled alder	*Alnus rugosa*	Sp, W
Sumac	*Rhus* spp.	W
Swamp honeysuckle	*Lonicera oblongifolia*	
Sweetfern	*Comptonia peregrina*	W
Sweet gale	*Myrica gale*	
Thimbleberry	*Rubus parviflorus*	

Thornapple	*Crataegus* spp.	
Trailing arbutus	*Epigea repens*	
Twinflower	*Linnaea borealis*	
Velvetleaf blueberry	*Vaccinium myrtilloides*	
Wild grape	*Vitis riparia*	
Wild plum	*Prunus americanus*	
Wild raisin	*Viburnum cassinoides*	
Willow	*Salix* spp.	Sp, Su, F, W
Wintergreen	*Gaultheria procumbens*	F, W
Witch hazel	*Hamamelis virginiana*	
Woodbine or virginia creeper	*Parthenocissus inserta*	

HERBACEOUS PLANTS:

Alfalfa	*Medicago sativa*	
American vetch	*Vicia americana*	
Arrowhead	*Sagittaria latifolia*	
Aster	*Aster* spp.	Su
Barren strawberry	*Waldsteinia fragaroides*	Su
Bedstraw	*Galium* spp.	
Black medic	*Medicago lupulina*	
Black snakeroot	*Saricula marilandica*	
Bladder campion	*Silene cucubalus*	
Bladderwort	*Utricularia* spp.	
Bluebell	*Mertensia paniculata*	
Bristly sarsaparilla	*Aralia hispida*	Su
Buckbean	*Menyanthes trifoliata*	Su
Buckwheat	*Fagopyrum* spp.	
Bunchberry	*Cornus canadensis*	F
Bur-reed	*Sparganium* spp.	
Clinton's lily	*Clintonia borealis*	
Clover	*Trifolium* and *Melilotus*	Su, F
Common dandelion	*Taraxacum officinale*	
Common geranium	*Geranium bicknellii*	
Common twisted-stalk	*Streptopus roseus*	
Composite family	*Compositae*	
Coontail	*Ceratophyllum demersum*	
Corn	*Zea mays*	
Cow parsnip	*Heracleum lanatum*	
Dock	*Rumex* spp.	
Early sweet pea	*Lathyrus ochroleucus*	Su
False lily-of-the-valley	*Maianthemum canadense*	
False Solomon's seal	*Smilacina trifolia*	
Filamentous algae	*Spirogyra* spp.	
Fireweed	*Epilobium angustifolium*	Su
Flat-top white aster	*Aster umbellatus*	
Forking catchfly	*Silene dichotoma*	
Fringed bindweed or false buckwheat	*Polygonum cilinode*	Su
Garden pea	*Pisum sativum*	
Goldenrod	*Solidago* spp.	Sp, Su, F
Goldthread	*Coptis groenlandica*	
Goosefoot	*Chenopodium* spp.	
Graminoids	*Gramineae and Cyperaceae*	
Grasses	*Gramineae*	Sp, Su, F
Harebell	*Campanula rotundifolia*	

Hawkweed	*Hieracium* spp.	
Hedge bindweed	*Convolvulus sepium*	
Hemp or marijuana	*Cannabis sativa*	
Horseweed	*Erigeron canadensis*	
Indian Hemp	*Apocynum cannabinum*	
Kidney bean	*Phaseolus* spp.	
Lady's thumb	*Polygonum persicaria*	
Large-leaf aster	*Aster macrophyllus*	Su, F
Lily family	*Liliaceae*	Sp, Su
Loosestrife	*Lysimachia* spp.	
Marsh cinquefoil	*Potentilla palustris*	
Marsh marigold	*Caltha palustris*	Sp
Milkweed	*Asclepias* spp.	
Night-flowering catchfly	*Silene noctiflora*	
Northern St. John's-wort	*Hypericum boreale*	
Pale touch-me-not	*Impatiens pallida*	
Pearly everlasting	*Anaphalis margaritaceae*	
Pigweed	*Amaranthus* spp.	
Pitcher plant	*Sarracenia purpurea*	
Purple watershield	*Brasenia schreberi*	
Pyrola	*Pyrola* spp.	
Ragweed	*Ambrosia* spp.	
Ribbonleaf pondweed	*Potamogeton epihydrus*	
Rough cinquefoil	*Potentilla norvegica*	Su
Scarlet columbine	*Aquilegia canadensis*	
Sedges	*Cyperaceae, including Carex* spp.	Sp, Su, F
Sheep sorrel	*Rumex acetosella*	
Showy smartweed	*Polygonum amphibium*	
Smooth aster	*Aster laevis*	
Solomon's seal	*Polygonatum* spp.	
Soybean	*Glycine max*	
Spikerush	*Eleocharis* spp.	
Spotted jewelweed	*Impatiens capensis*	Su
Spreading dogbane	*Apocynum androsaemifolium*	Su
Strawberry	*Fragaria* spp.	Su
Sunflower	*Helianthus* spp.	
Sweet clover	*Melilotus* spp.	
Sweet pea	*Lathyrus* spp.	Su
Sweet water-parsnip	*Sium sauve*	
Thistle	*Cirsium* spp.	
Three-way sedge	*Dulichium* spp.	
Violet	*Viola* spp.	Su
Water horsetail	*Equisetum fluviatile*	
Water milfoil	*Myriophyllum* spp.	Su
Wheat	*Triticum aestivum*	
White clover	*Trifolium repens*	
Wild carrot or Queen Anne's lace	*Daucus carota*	
Wild lettuce	*Lactuca canadensis*	
Wild rice	*Zizania aquatica*	
Wild sarsaparilla	*Aralia nudicaulis*	Su
Wild sweet pea	*Lasthyrus venosus*	Su
Wood anemone	*Anemone quinquefolia*	
Yarrow	*Achillea millifolium*	

Yellow bellwort	*Uvularia grandiflora*				
Yellow trout lily	*Erthronium americanum*				
FUNGI:					
Bracket fungi	*Daedalia* spp. *Lenzites* spp. *Polyporus* spp. *Schizophyllum* spp.				
Mushrooms			Su		
LICHENS:					
Old man's beard	*Usnea* spp.				
Arboreal lichens[2]	Mainly *Usnea* spp. and *Evernia* spp.				W
FERNS AND FERN ALLIES:					
Bracken fern	*Pteridium aquilinum*		Su		
Clubmoss	*Lycopodium* spp.				
Grape fern	*Botrychium* spp.				
Shield fern	*Dryopteris* spp.				
Wood fern	*Dryopteris* spp.				
Mosses	*Unidentified mosses*				
Pigeonwheat moss	*Polytrichum* spp.				

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[1] Season of use is designated only for those species found to comprise 5 percent or more of the diet in at least one study in the given season. Sp = April-May, Su = June-September, F = October-November, W = December-March.

[2] Alectoria spp. was reported as eaten in one study but later was found to be a misidentification of Usnea spp. and Evernia spp. lichens.

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Rogers, Lynn L., Jack J. Mooty, and Deanna Dawson.

1981. Foods of white-tailed deer in the Upper Great Lakes Region—a review. U.S. Department of Agriculture Forest Service, General Technical Report NC-65, 24 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Available information on year-round food habits of white-tailed deer in the Upper Great Lakes Region (UGLR) is summarized. Problems of deer in that region are discussed. There is a need for additional information on year-round diet, but new study techniques must be developed if a complete picture of diet is to be obtained.

KEY WORDS: year-round diet, starvation, predation, reproduction, winter conditions, study techniques.

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A net volume equation for northeastern Minnesota

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A NET VOLUME EQUATION FOR NORTHEASTERN MINNESOTA

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A net merchantable tree volume equation and coefficients were developed for the Aspen-Birch Unit of northeastern Minnesota as part of the 1977 Minnesota Forest Inventory (fig. 1). The equation is suitable for use on digital computers by foresters, land managers, researchers, and others in need of net volume-per-tree estimates over large forest areas. Both board foot and cubic foot volume can be estimated for most tree classes.

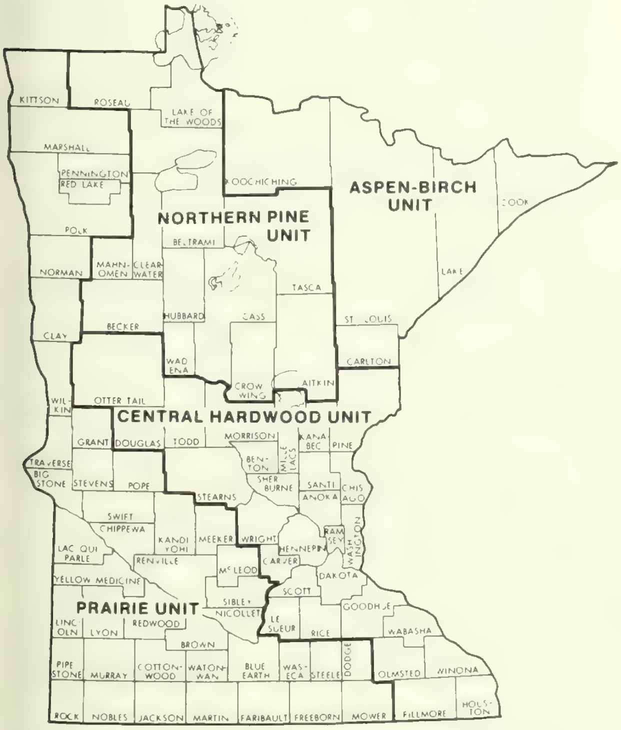

Figure 1.—*Forest Inventory Units for Minnesota.*

HOW THE EQUATION AND COEFFICIENTS WERE DEVELOPED

Equations developed by Robert N. Stone (see Appendix) based on Gevorkiantz and Olsen's (1955) composite volume tables for the Lake States were used to estimate the cubic foot volume in each tree. Stone's equations computed gross volume in a tree from the three measurements—diameter breast height (d.b.h.), merchantable height, and diameter outside bark at merchantable height (t.d.o.b.). This estimated volume was then corrected for differences in bark thickness between species and the field estimate of cull volume was subtracted to arrive at net volume (see Appendix for Stone's equation).

Experience in working with volume-d.b.h. relations suggests the following equation for this type of data (Hahn 1975, 1976):

$$V = A \cdot SI \cdot (1 - e^{-B \cdot DBH})^{C}$$

Where the dependent variable V is net volume of the tree, and the independent variables SI and DBH are plot site index and diameter at breast height, respectively. The value of e is the constant base of the natural logarithm (2.71828). A, B, and C are the equation coefficients. The upper asympote, A•SI, is a function of site index.

The equation coefficients were developed using data collected by field crews on 18,158 trees in the Aspen-Birch Unit. Data included d.b.h., merchantable height, t.d.o.b., site index, and tree class. For sawtimber-size trees, measurements were taken at both the sawtimber and pulpwood limits of merchantability.[1] Field crews also estimated the volume of board foot and cubic foot cull in each tree (USDA Forest Service 1975).

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[1] *The pulpwood merchantability limits include trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum of 4-inch t.d.o.b., or to the point where the central stem breaks into limbs. Dimensions for sawtimber are 9-inch d.b.h. to a minimum 7-inch t.d.o.b. and 11-inch d.b.h. to a minimum 9-inch t.d.o.b. for softwoods and hardwoods, respectively (USDA Forest Service 1975).*

Equation coefficients were developed for each of five tree classes: "desirable," "acceptable," "rough," "rotten," and "short-log" (see Appendix). Equation coefficients were also developed for board foot[2] and cubic foot volume (79 cubic feet per cord).

The groupings of species for the equations were primarily determined by the number of observations and the similarity of bole form among species. Species for which no observations were available were assigned equations on the basis of bole form. (For species and group numbers see Appendix.)

A computerized nonlinear regression program was used to fit the above equation to the tree data. The resulting coefficients and statistics for each regression are given in tables 1-10. Note the standard error is the standard error of the regression.

Since the average site index may be used when site index is unknown, the only data needed to determine tree volumes using this model are species, d.b.h., and tree class. Most trees in Minnesota are classed as "acceptable," with very few "desirable" trees; therefore, the person wishing to use only one equation for woods-run material should use the equation for "acceptable" trees. Net volume per tree is highly variable therefore these equations should be applied to an adequate sample over large forest areas.

HOW TO USE THE EQUATION

1. Obtain the species group number from th Appendix.
2. Select the appropriate coefficients from table 1-10.
3. Use these coefficients in the above equation.

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APPENDIX

METRIC EQUIVALENTS

1,000 board feet = 3.48 cubic meters.
Breast height = 1.37 meters above the ground.
1 cubic foot = 0.0283 cubic meter.
1 foot = 30.48 centimeters or 0.3048 meter.
1 inch = 25.4 millimeters or 2.54 centimeters or 0.0254 meter.

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[2] *International ¼-inch rule.*

VOLUME EQUATIONS

Stone's cubic foot volume equation uses the following independent variables: diameter at breast height (D), merchantable height (H), and diameter outside bark at merchantable height (T) to estimate cubic foot volume (CV).

$$CV = (3.0886 \times 10^{-3} + S1 + S2 + S3 + S4 + S5 + S6 + S7 + S8) \cdot 79.0$$

where

$S1 = (2.0355 \times 10^{-3})D$
$S2 = (-3.0018 \times 10^{-3})T$
$S3 = (6.2381 \times 10^{-5})D^2$
$S4 = (2.5705 \times 10^{-5})D^2 \cdot H$
$S5 = (-7.009 \times 10^{-6})H^2$
$S6 = (3.6708 \times 10^{-5})H \cdot T^2$
$S7 = (8.14 \times 10^{-10})D^2 \cdot H^3$
$S8 = (-1.9 \times 10^{-9})D^2 \cdot H^2 \cdot T$

Stone's board foot volume equation as modified by Hahn (1975, 1976) is as follows:

$$BV = 17.7488 + 7.3846 \cdot CV - 2.3523 \cdot D - 0.89945 \cdot H + 2.0726 \cdot T$$

where

BV = board foot volume.

DEFINITION OF TERMS

(USDA Forest Service 1975)

Desirable trees.—Live trees that have no serious defects that limit present or prospective use and that have relatively high vigor and contain no pathogens that may result in death or serious deterioration before rotation age. They would be favored by forest managers in silvicultural operations.

Acceptable trees.—Live trees having no serious defects that limit present or prospective use but that have pathogens or damage that may affect quality.

Rough trees.—Live trees that do not contain at least one merchantable 12-foot saw log, now or prospectively, because of roughness, poor form, or noncommercial species.

Rotten trees.—"Rough" trees in which more than 50 percent of the cull volume is rotten.

Short-log trees.—Live sawtimber sized trees that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log, now or prospectively.

SPECIES AND SPECIES GROUPS FOR MINNESOTA TREES

Number	Species or species group	Scientific name
SOFTWOODS		
1	White pine	*Pinus strobus*
2	Red pine	*Pinus resinosa*
3	Jack pine	*Pinus banksiana*
4	White spruce	*Picea glauca*
5	Black spruce	*Picea mariana*
6	Balsam fir	*Abies balsamea* var. *balsamea*
7	Tamarack	*Larix laricina*
8	Northern white-cedar	*Thuja occidentalis*
9	Other softwoods	*Pinus sylvestris* *Juniperus virginiana*
HARDWOODS		
10	White oak	*Quercus alba* *Quercus bicolor* *Quercus macrocarpa*
11	Select red oak	*Quercus rubra*
12	Other red oak	*Quercus ellipsoidalis*
13	Hickory	*Carya cordiformis* *Carya ovata*
14	Yellow birch	*Betula alleghaniensis*
15	Hard maple	*Acer nigrum* *Acer saccharum*
16	Soft maple	*Acer rubrum* var. *rubrum* *Acer saccharinum*
17	Ash	*Fraxinus americana* *Fraxinus nigra* *Fraxinus pennsylvanica*
18	Balsam poplar	*Populus balsamifera*
19	Paper birch	*Betula papyrifera* var. *papyrifera*
20	Bigtooth aspen	*Populus grandidentata*
21	Quaking aspen	*Populus tremuloides*
22	Basswood	*Tilia americana*
23	Elm	*Ulmus americana* *Ulmus rubra* *Ulmus thomasii*
24	Select hardwoods	*Juglans cinerea* *Juglans nigra* *Prunus serotina*
25	Other hardwoods	*Acer negundo* *Betula nigra* *Celtis occidentalis* *Populus deltoides* *Salix nigra*
26	Noncommercial species	

Table 1.—Net cubic foot volume regression coefficients for desirable trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average	Range of data		Number observa-tions	Standard error (cu. ft.)
	A	B	C	Site index	Site index	D.b.h.		
1-3(9)[1]	2.154×10^{3}	0.00651	3.52	53.5	22-80	5.2-32.0	37	19.8
5(4)[1]	6.400×10^{1}	.00460	1.78	37.6	25-86	5.0-18.6	32	2.8
6-8	9.152×10^{-1}	.24112	11.45	46.4	16-82	5.2-20.4	36	3.3
14,16,17,19,22,23, (10-13, 15,24,25)[1]	8.300×10^{1}	.00830	2.44	57.0	25-95	5.0-22.0	102	3.6
18,20,21	4.177×10^{2}	.00492	2.59	68.7	29-98	5.2-19.7	218	3.4

[1] Data were not available for species groups in parentheses.

Table 2.—Net cubic foot volume regression coefficients for acceptable trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average	Range of data		Number observa-tions	Standard error (cu. ft.)
	A	B	C	Site index	Site index	D.b.h.		
1	2.897×10^{9}	0.00005	3.13	52.6	22-99	5.2-35.9	197	28.1
2	1.665×10^{0}	.09460	4.23	55.7	37-75	5.0-23.0	249	4.9
3(9)[1]	3.747×10^{3}	.00133	2.31	56.9	26-80	5.0-18.1	330	2.8
4	1.421×10^{3}	.00233	2.38	57.1	22-91	5.0-25.0	321	6.8
5	2.036×10^{6}	.00023	2.61	39.3	16-86	5.0-19.8	1,479	3.1
6	2.422×10^{5}	.00026	2.40	56.4	18-98	5.0-19.8	2,163	2.0
7	1.304×10^{0}	.10503	4.06	38.9	16-75	5.0-15.1	571	1.9
8	1.664×10^{0}	.09093	4.29	33.7	16-89	5.0-25.7	603	4.4
10,11(12,13,24,25)[1]	6.232×10^{1}	.01262	2.88	59.0	36-81	5.0-15.8	41	1.8
14,19	1.874×10^{5}	.00021	2.27	59.0	19-99	5.0-23.0	1,912	2.8
15	1.366×10^{5}	.00019	2.21	59.3	46-99	5.0-18.4	162	1.6
16	7.996×10^{6}	.00014	2.73	60.2	35-91	5.0-15.2	152	1.6
17	3.122×10^{5}	.00026	2.44	52.0	18-99	5.0-23.6	603	3.1
18	5.663×10^{3}	.00102	2.30	64.9	26-99	5.0-23.0	897	2.8
20	5.328×10^{5}	.00031	2.63	63.2	35-91	5.0-22.8	131	4.2
21	1.617×10^{5}	.00020	2.23	66.6	23-99	5.0-24.9	3,478	3.3
22	1.790×10^{3}	.00170	2.30	59.2	36-99	5.0-20.2	131	3.2
23	6.920×10^{4}	.00052	2.50	59.1	40-98	5.1-24.0	155	6.1

[1] Data were not available for species groups in parentheses.

Table 3.—Net cubic foot volume regression coefficients for rough and short-log trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average Site index	Range of data		Number observations	Standard error (cu. ft.)
	A	B	C		Site index	D.b.h.		
1-3,9	2.193×10^{3}	0.00133	2.23	54.8	33-75	5.1-18.5	52	2.6
4,5	5.289×10^{-1}	.14938	4.67	39.7	20-78	5.0-13.4	63	1.8
6	6.705×10^{-1}	.08917	3.03	52.6	19-82	5.0-16.2	135	1.7
7	7.936×10^{-1}	.09784	2.96	40.7	19-68	5.0-16.7	47	2.6
8	8.175×10^{-1}	.12157	5.24	36.3	16-98	5.0-19.0	209	4.0
11,15,24-26 (10,12,13)[1]	9.267×10^{-1}	.11819	5.80	58.0	38-77	5.0-21.9	84	1.7
14,19	6.964×10^{-1}	.13971	5.68	57.9	21-99	5.0-22.3	276	2.9
16	7.831×10^{-1}	.12297	5.74	61.2	38-87	5.0-20.6	92	1.7
17	1.636×10^{0}	.10525	6.01	48.0	29-75	5.0-13.6	61	1.7
18,20,21	6.407×10^{-1}	.13405	5.60	65.6	29-99	5.0-23.7	463	3.4
22,23	6.199×10^{0}	.06672	6.82	54.8	40-85	5.0-40.2	44	5.2

[1] Data were not available for species groups in parentheses.

Table 4.—Net cubic foot volume regression coefficients for rotten trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average Site index	Range of data		Number observations	Standard error (cu. ft.)
	A	B	C		Site index	D.b.h.		
1,3-5(2,9)[1]	3.084×10^{0}	0.05940	5.30	43.2	22-70	5.2-21.4	31	4.5
6,7	5.590×10^{-1}	.10190	4.76	49.0	18-70	5.0-14.7	79	3.4
8	4.386×10^{-1}	.07417	3.52	37.2	16-98	5.0-27.3	270	4.6
10,11,15,24,25 (12,13,26)[1]	2.458×10^{0}	.05138	6.01	55.5	36-77	5.1-25.3	98	8.0
14	1.502×10^{-1}	.10573	6.31	55.6	25-75	5.8-28.1	55	7.1
16	6.660×10^{0}	.04680	5.61	58.0	38-87	5.0-21.8	1,142	4.3
17	7.845×10^{-2}	.19333	4.04	48.4	25-82	5.0-22.9	46	4.2
18,20,21	4.962×10^{-1}	.03528	1.73	63.7	29-99	5.0-28.9	694	6.9
19	1.606×10^{-1}	.17045	5.80	51.1	22-83	5.0-27.5	171	5.7
22,23	1.445×10^{-1}	.18231	5.94	56.1	35-82	5.1-34.4	46	7.5

[1] Data were not available for species groups in parentheses.

Table 5.—Net board foot[1] volume regression coefficients for desirable trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average	Range of data		Number	Standar
	A	B	C	Site index	Site index	D.b.h.	observations	error (bd. ft.)
1-3,5,7,8(4,6,9)[2]	3.643×10^5	0.00087	2.61	49.7	16-86	9.6-32.0	50	165.5
14,16,17,19,22,23 (10,13,15,24,25)[2]	2.046×10^3	.00336	2.23	57.8	25-82	11.2-22.0	40	41.9
18,20,21	2.064×10^3	.00337	2.24	68.7	36-98	11.0-19.7	76	34.7

[1] International ¼-inch rule.
[2] Data were not available for species groups in parentheses.

Table 6.—Net board foot[1] volume regression coefficients for acceptable trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average	Range of data		Number	Standard
	A	B	C	Site index	Site index	D.b.h.	observations	error (bd. ft.)
1	8.873×10^4	0.00130	2.62	52.6	22-99	9.3-35.9	178	207.3
2	1.614×10^4	.00054	1.80	54.4	37-75	9.1-23.0	162	36.5
3(9)[2]	5.018×10^3	.00261	2.40	58.1	33-80	9.1-18.1	163	21.6
4	2.379×10^6	.00060	2.96	57.3	22-91	9.0-25.0	210	47.8
5	3.544×10^6	.00069	3.03	44.0	16-86	9.0-19.8	195	39.7
6,7	3.989×10^3	.00233	2.26	56.3	16-88	9.0-19.8	554	20.5
8	3.869×10^3	.00251	2.21	34.7	16-89	9.0-25.7	680	39.7
10,11,15,16 (12,13,24,25)[2]	2.180×10^4	.00037	1.80	58.5	43-82	11.0-18.4	53	24.6
14,19	7.328×10^3	.00051	1.68	57.4	19-99	11.0-23.0	253	39.6
17	8.908×10^3	.00048	1.65	50.1	21-99	11.0-23.6	99	48.2
18	4.059×10^5	.00019	2.08	64.5	26-98	11.0-23.0	251	33.5
20,21	9.322×10^2	.00566	2.43	68.1	23-99	11.0-24.9	1,009	40.1
22	7.791×10^2	.00548	2.35	58.3	40-83	11.0-20.2	38	45.5
23	1.007×10^5	.00110	2.63	56.6	40-84	11.0-24.0	94	51.0

[1] International ¼-inch rule.
[2] Data were not available for species groups in parentheses.

Table 7.—Net board foot[1] volume regression coefficients for short-log trees, Aspen-Birch Unit, Minnesota, 1977

pecies group number	Coefficient			Average Site index	Range of data		Number observations	Standard error (bd. ft.)
	A	B	C		Site index	D.b.h.		
-7(9)[2]	5.502×10^{-1}	0.10168	4.93	52.6	35-82	9.0-16.7	50	37.5
	2.445×10^{0}	.06232	1.71	38.9	20-98	9.0-19.0	55	29.6
1,14,16,17,19,22,23 (10,12,13,15,24-26)[2]	1.846×10^{1}	.05735	5.02	57.6	38-83	11.0-40.2	41	40.1
8,20,21	2.963×10^{5}	.00014	2.06	67.7	36-99	11.1-20.0	70	31.1

International ¼-inch rule.

Data were not available for species groups in parentheses.

Table 8.—Net cubic foot volume in saw log regression coefficients for desirable trees, Aspen-Birch Unit, Minnesota, 1977

pecies group number	Coefficient			Average Site index	Range of data		Number observations	Standard error (cu. ft.)
	A	B	C		Site index	D.b.h.		
-3,5,7,8 (4,6,9)[1]	1.056×10^{4}	0.00148	2.53	49.7	16-86	9.6-32.0	50	23.9
4,16,17,19,22,23 (10-13,15,24,25)[1]	2.200×10^{3}	.00158	2.31	57.8	25-82	11.2-22.0	40	6.3
8,20,21	3.049×10^{3}	.00185	2.49	68.7	36-98	11.0-19.7	76	5.5

Data were not available for species groups in parentheses.

Table 9.—Net cubic foot volume in saw log regression coefficients for acceptable trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average	Range of data		Number observations	Standard error (cu. ft.)
	A	B	C	Site index	Site index	D.b.h.		
1	3.472×10^{3}	0.00191	2.50	52.6	22-99	9.3-35.9	178	29.7
2	4.255×10^{3}	.00028	1.66	54.4	37-75	9.1-23.0	162	6.1
3(9)[1]	2.275×10^{3}	.00170	2.38	58.1	33-80	9.1-18.1	163	3.7
4	1.550×10^{3}	.00064	1.78	57.3	22-91	9.0-25.0	210	8.2
5	1.663×10^{3}	.00149	2.14	44.0	16-86	9.0-19.8	195	7.2
6,7	1.756×10^{3}	.00147	2.25	56.3	16-88	9.0-19.8	554	3.6
8	1.521×10^{3}	.00141	2.10	34.7	16-89	9.0-25.7	680	6.8
10,11,15,16 (12,13,24,25)[1]	5.096×10^{3}	.00015	1.60	58.5	43-82	11.0-18.4	53	3.5
14,19	1.187×10^{3}	.00013	1.32	57.4	19-99	11.0-23.0	253	6.7
17	2.457×10^{3}	.00019	1.48	50.1	21-99	11.0-23.6	99	8.8
18	1.584×10^{3}	.00015	1.40	64.5	26-98	11.0-23.0	251	6.1
20,21	3.185×10^{2}	.00303	2.20	68.1	23-99	11.0-24.9	1,009	5.9
22	2.629×10^{2}	.00284	2.10	58.3	40-83	11.0-20.2	38	6.0
23	3.435×10^{4}	.00054	2.40	56.6	40-84	11.0-24.0	94	8.0

[1] Data were not available for species groups in parentheses.

Table 10.—Net cubic foot volume in saw log regression coefficients for short-log trees, Aspen-Birch Unit, Minnesota, 1977

Species group number	Coefficient			Average	Range of data		Number observations	Standard error (cu. ft.)
	A	B	C	Site index	Site index	D.b.h.		
1-7(9)[1]	6.107×10^{2}	0.00194	2.21	52.6	35-82	9.0-16.7	50	6.3
8	1.071×10^{2}	.00146	1.59	38.9	20-98	9.0-19.0	55	6.0
11,14,16,17,19,22,23 (10,12,13,15,24-26)[1]	4.456×10^{2}	.00228	2.27	57.6	38-83	11.0-40.2	41	4.4
18,20,21	5.795×10^{1}	.00092	1.33	67.7	36-99	11.1-20.0	70	4.9

[1] Data were not available for species groups in parentheses.

Raile, Gerhard K.

1980. A net volume equation for Northeastern Minnesota. U.S. Department of Agriculture Forest Service, General Technical Report NC-66, 8 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Describes a net volume equation for northeastern Minnesota developed as part of the 1977 Minnesota Forest Inventory. Equation coefficients are presented by species groupings for both cubic foot and board foot volumes for five tree classes.

KEY WORDS: inventory, computer, growing-stock, cull, cubic foot volume, board foot volume.

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General Technical Report NC-67

Database Management:

a Forest Inventory Application

Dennis L. Murphy

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DATABASE MANAGEMENT: A FOREST INVENTORY APPLICATION

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Forest Survey inventories provide data for a variety of users, including private and public forest managers, forest scientists, and the general public. Because user needs have changed in recent years, one standard set of tables no longer provides adequate information. In attempting to find a faster and more flexible method for responding to special requests for inventory data, a study of database designs was initiated using forest inventory data from Minnesota's Aspen-Birch Forest Survey Unit. Two databases were created, representing two levels of information detail. The databases were compared with each other and with standard forest inventory retrieval methods to evaluate their cost-effectiveness and ability to satisfy user demands.

The evaluation was based on the costs incurred at the University of Minnesota Computer Center. The center operates two Control Data Corporation computers: models Cyber 74 and Cyber 172.[1] Both computers utilize the NOS operating system software. Although costs at other installations will vary, the results will provide the reader with levels of the costs of creating, operating, and applying the databases.

DATABASE MANAGEMENT SYSTEMS

Many disciplines have experienced changes in user information requirements. In the 1950's and 1960's, data processors designed data files within individual programs (Sibley 1976), creating a situation of limited user access to the data. This method of designing data files also led to duplication of data, since individual programs tended to have their own files for data storage.

Problems with data access gradually led to the concept of the integrated database. Software systems were developed that provided integrated data structures, separate access languages for nonprogrammers and programmers, and data integrity functions (Everest 1976). Moser (1976) demonstrated the application of a database management system (DBMS) to an operational forest inventory, the compartment examination. Meteer (1975) argued that a second type of forest inventory, the planning inventory, could also benefit from increased user access and report flexibility. A database management system can provide the benefits of flexible access while also providing data integrity functions to control the quality and use of the data resource within an organization.

The database management system used in this study was System 2000 (MRI Corporation 1974). Two trial databases for Minnesota's Aspen-Birch Unit were developed, one from the tree detail file and one from the plot summary file. Data from the fourth Minnesota Forest Inventory (1977) supplied input to the databases. The following steps were taken to create each database.

Designing the Database

Two major factors must be considered in designing a database: (1) the logical design, and (2) the physical consequences of the design.

The former requires the analyst to identify the entities to be stored in the database, the attributes of each, and the relations among them. This step involves comparing the effectiveness of various designs in processing anticipated reports.

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[1] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

The second factor involves estimating the physical storage space required for the database. Every design has a physical consequence; for example, a database created in System 2000 physically exists as six random access files. The size of these files is a direct consequence of the logical design for the database, and can be estimated using ESTIMANUAL (MRI Corporation 1974). In this study a program[2] was available from the University of Minnesota Computer Center to calculate size estimates, which were then used to evaluate design alternatives.

The choice of a design for this study involved a trade-off between processing flexibility and cost of the physical storage space required. The logical design selected accommodated the major anticipated reports while using storage space most efficiently.

Defining the Database

The conceptual structure of the entities was translated into a physical data structure in the data definition language of System 2000. To the new user of a database management system, this step will not be an obvious one. However, the database must be defined before the data can be converted into the standard internal format of System 2000.

Creating the Database

A FORTRAN PLI program was written to convert the data to the internal format. PLI is a System 2000 software package that provides an interface between a FORTRAN program and the database.

Establishing Administrative Procedures

Administration of the database involves ensuring data security and integrity. User access can be restricted by assigning passwords to sensitive elements; for example, the location of an inventory plot in the case of private ownership. Providing a backup copy of the database on magnetic tape ensures against accidental destruction.

Providing Documents for User Interface

Two manuals were written for subsequent use o the database management system.[3] The first, a database manager's guide, outlines the steps required t define, create, and archive the database. With thi manual, data management personnel can create databases for other survey units. The second manual i the user's guide. This manual contains introductor information for the new user, a description of th data, and reference material for access languages Both of the manuals are essential to the implementation of the database management system.

RESULTS

Plot Summary Database

Description

The database structure selected from the availabl alternatives was a two-level, single-path heirarchy The first level contains plot attributes (e.g., stand age, acres, forest type, site index). The second level contains species group attributes (e.g., species grou code, number of trees per acre, growing stock volum per acre in cubic feet and board feet). A graphical representation of the data structure specifying attributes accessible at each level is called a schema diagram (fig. 1). The relation of the plot data attributes to the species group attributes is one-to-many the number of species groups for a plot equals the number of species groups measured on that plot. When database size was estimated, it was assumed that there would be six species groups per plot. This assumption was high; the average was about four species groups per plot. The estimated size was 9.5 million characters while the actual size was 6.5 million characters.

Use

The plot summary database can be used to answer two types of requests: simple retrievals (queries) and reports. A user may be interested in a listing of data for plots meeting specific characteristics; this is a simple retrieval. For example, a resource analyst requested a listing of plot numbers, acres per plot, and ground land use for plots located in what was formerly known as the portal zone of the Boundary Waters Canoe Area. The results are shown below. The data were retrieved and printed at a cost of $0.15. The retrievals involved about 5 minutes of an individual's time at the terminal.

---

[2] *S2KESTM, a FORTRAN program which estimates System 2000 database files.*

[3] *The manuals document procedures for office personnel. They are not formal publications.*

Plot No.	Acres/plot	Ground land use code[4]
528	1,246	20
533	1,330	20
535	1,371	20
536	1,371	20
540	1,395	20
541	1,161	90
542	1,395	20
543	1,625	20
661	1,537	20
662	1,537	20
664	5,449	80
2804	1,648	20
2836	1,451	20
2839	1,395	20
2842	1,395	20
2843	1,371	20
3208	1,566	65
3220	1,211	20
3223	1,451	20
3224	1,451	20
3235	1,371	20
3237	1,537	20
3238	1,625	20
3239	1,648	20
3241	1,395	20
5010	1,627	40

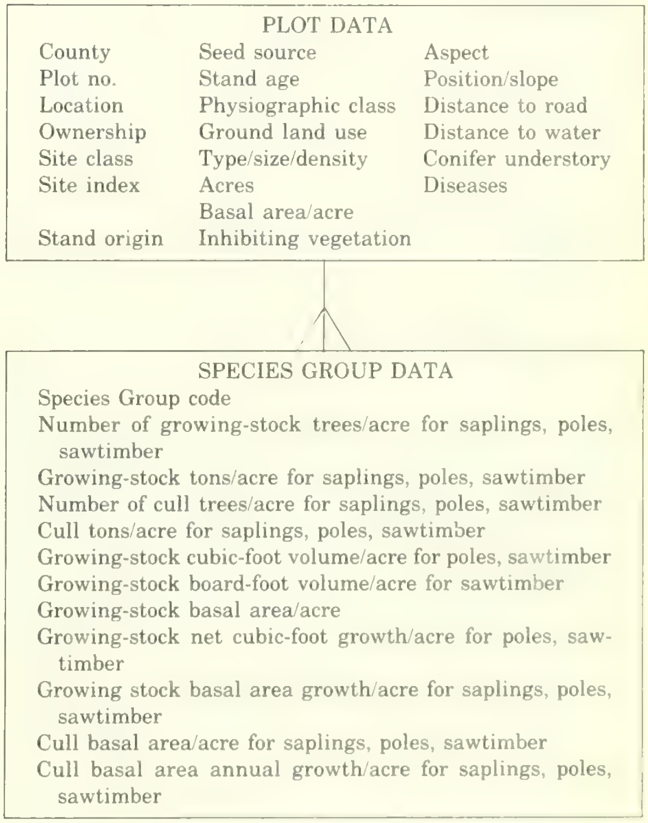
A second query came from a research forester who wanted to obtain the range of site index values for each of 14 forest types. The questioner constructed commands to print the minimum value, the maximum value, the average value, and the standard deviation. An example of the output for one forest type, jack pine, is shown below (18* signifies site index):

```
MIN 18* 38
MAX 18* 80
AVG 18* 56.000
SIG 18* 9.724
```

The total cost of calculating these values for 14 forest types was $11.50 (56 values; an average of $0.21 for each value). The operation involved about an hour at an interactive terminal.

Formal summary reports are more appropriately produced via the Report Writer module of System 2000 or a procedural language applications program. Resource inventory data are commonly used to provide summary tables. These tables can be produced in the Report Writer language for reasonable cost and with considerable flexibility. The report commands, like the retrievals, can be written at an interactive terminal. Two examples of tables produced by Report Writer are given below.

A request was received for summary tables of acreage by site productivity, age, and basal area categories for several forest types. The results, shown in Table 1, cost $1.50 per table. Table 1 also indicates treatment opportunities in the survey unit. For example, in stands with a site productivity of 85 to 120 cu ft/acre/year, approximately 6,829 acres had sufficient basal area for thinning. The table has the potential added benefit of grouping plot data for later



PLOT DATA

County
Plot no.
Location
Ownership
Site class
Site index
Stand origin
Seed source
Stand age
Physiographic class
Ground land use
Type/size/density
Acres
Basal area/acre
Inhibiting vegetation
Aspect
Position/slope
Distance to road
Distance to water
Conifer understory
Diseases

SPECIES GROUP DATA

Species Group code
Number of growing-stock trees/acre for saplings, poles, sawtimber
Growing-stock tons/acre for saplings, poles, sawtimber
Number of cull trees/acre for saplings, poles, sawtimber
Cull tons/acre for saplings, poles, sawtimber
Growing-stock cubic-foot volume/acre for poles, sawtimber
Growing-stock board-foot volume/acre for sawtimber
Growing-stock basal area/acre
Growing-stock net cubic-foot growth/acre for poles, sawtimber
Growing stock basal area growth/acre for saplings, poles, sawtimber
Cull basal area/acre for saplings, poles, sawtimber
Cull basal area annual growth/acre for saplings, poles, sawtimber

Figure 1.—*Plot summary database schema diagram.*

---

[4] *Definition of ground land uses: 20, plot previously designated as commercial forest; 40, productive reserve; 65, marsh; 80, noncensus water; 90, census water.*

Table 1.—*Commercial forest area of red pine forest type, summarized by site productivity, age, and basal are classes, Minnesota Aspen-Birch Unit, 1977 data*
(In acres)

Site productivity (potential cubic-foot per acre per year (MAI) and age class (years)	Basal area (square feet/acre) 30	60	90	120	150	180	Total
120-165 cu ft							
31-40			1,364				1,364
Subtotal			1,364				1,364
85-120 cu ft							
21-30				1,178			1,178
31-40					2,698		2,698
41-50				1,797			1,797
51-60					2,759		2,759
81-90					1,372		1,372
Subtotal				2,975	6,829		9,804
50-85 cu ft							
0-10			1,567				1,567
11-20	2,878						2,878
31-40			1,372				1,372
41-50					2,766		2,766
51-60			1,451				1,451
61-70				4,012			4,012
71-80						7,971	7,971
81-90		1,323					1,323
91-100					1,139		1,139
101-120		1,330					1,330
Subtotal	2,878	2,653	4,390	4,012	3,905		7,971
20-50 cu ft							
41-50			1,371				1,371
61-70			1,324				1,324
81-90	1,451						1,451
121-140						1,371	1,371
Subtotal	1,451		2,695			1,371	5,517
Total	4,329	2,653	8,449	6,987	10,734	9,342	42,494

input into a linear programming module. (Data management personnel would modify the program to provide growing stock volume in addition to acreage.)

Several forest land managers responsible for managing properties within the Aspen-Birch Unit requested a table summarizing acreage by site index, forest type, and stand-age class for specific ownership and stocking levels (table 2). This is another example of a summary report using the Report Writer module. The cost of producing this table was $21.00. The Report Writer module was modified to produce tables for two stocking levels and three ownership classes, for a total of six tables.

Figure 2 demonstrates another capability of the system: an interface with an applications program. A simple Report Writer command file was written t summarize acreage by stand-age class for a specifi forest type. The system created an intermediate dat file which was used as an interface between th database and the graphing package. The total cost o retrieving the appropriate survey plots and plottin the histogram was $1.50.

Costs

The initial cost of computer processing for estab lishing the Aspen-Birch Unit[5] plot summary data

---

[5] *The unit contains 4,907 plots.*

Table 2.—*Commercial forest area by forest type, age, and site index, for good/medium stocked stands, on public ownership excluding national forest, within the Minnesota Aspen-Birch Unit, 1977 data (only a portion of the table shown here)*

(In thousand acres)

Forest type and age class	**Site index**								
	0-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total
Jack pine:									
0-10				1.2					1.2
21-30			1.6		1.3				2.9
31-40				3.0	2.8	1.4			7.2
41-50				4.1		1.0			5.1
51-60				4.2					4.2
61-70		1.5	1.8	1.4					4.7
Subtotal	1.5	3.4	13.9	4.1	2.4			25.3	
Red pine:									
0-10				1.6					1.6
11-20				2.8					2.8
21-30						1.2			1.2
31-40					1.2				1.2
61-70		1.3	1.4						2.7
Subtotal		1.3	1.4	4.4	1.2	1.2			9.5
White pine:									
11-20				1.4					1.4
Subtotal				1.4					1.4
Black spruce:									
0-10	3.7	2.6	1.2						7.5
11-20	16.6	9.8	14.6	1.4					42.4
21-30	28.1	39.7	11.8	1.2					80.8
31-40	33.6	22.0	13.2	2.5					71.3
41-50	17.0	8.9	8.1	3.8					37.8
51-60	17.6	7.7	12.0	1.3					38.6
61-70	8.0	9.3	9.8	4.2	1.3				32.6
71-80	12.2	13.3	8.4						33.9
81-90	8.6	8.4	4.1						21.1
91-100	14.8	5.1	1.4						21.3
101-120	8.6	4.1							12.7
121-140	1.4	5.5							6.9
Subtotal	170.2	136.4	84.6	14.4	1.3				406.9

base was $122.50. This cost does not include the purchase price of System 2000 or the cost of initial software development for the load program.

Initial costs:

Definition	$ 2.50
Creation	
Load	50.00
Index	50.00
Archive	20.00
Total	$122.50

A daily disk storage cost of $7.00 would be incurred if the database were maintained on disk for the entire operating day of the computer system. Considering the low cost of copying the database from magnetic tape to disk storage ($2.50 for the entire database), the database was stored on disk only when needed.

Operating costs:

Daily disk storage	$ 7.00
Copy from tape to disk	2.50
Release	.05
Retrievals and reports	variable

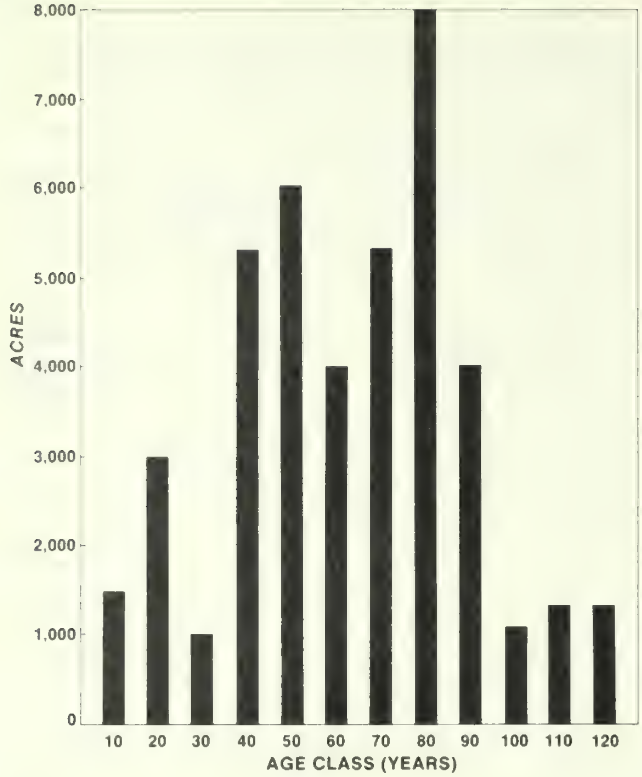


Figure 2.—*Acres of red pine forest type by stand age class, all ownerships, Minnesota Aspen-Birch Unit, 1977.*

Evaluation

The cost of the plot summary database approach was compared with that of conventional data processing for queries and summary tables. The comparison for simple queries is given below based on the example of site index ranges given previously.

	Present method	Query language (database)
Programming	$32.00	$ 8.00
Computer time	2.00	12.00
Copy to disk & 1 hour storage	—	3.50
Total	34.00	23.50
Fixed cost of creating database	—	$122.50

The major difference between the two methods is in programming time; the query language reduces programming time by 75 percent and serves the nonprogramming user. The difference in personnel time was estimated at 3 hours, or $24.00.[6] The computer time to produce the same result by use of FORT program was not readily available. The cost assumed to be no more than $2.00, based on available programs. The use of the database inv the cost of copying the database to disk and stori for 1 hour, as well as a fixed creation cost of $12 Figure 3 compares conventional costs with dat costs for a varying number of requests per year break-even point is about 12 requests per year; that, the database becomes the most cost-effe method.

The costs of the two alternatives for produ summary tables are presented below:

	Present method	Report Wr (databas
Programming	$128.00	$ 65.00
Computer time	5.00	10.00
Copy to disk & 1 hour storage	—	3.50
Total	133.00	78.50
Fixed cost of creating database		122.50

Survey personnel estimated it would take 2 da write a program for a special request. A sim

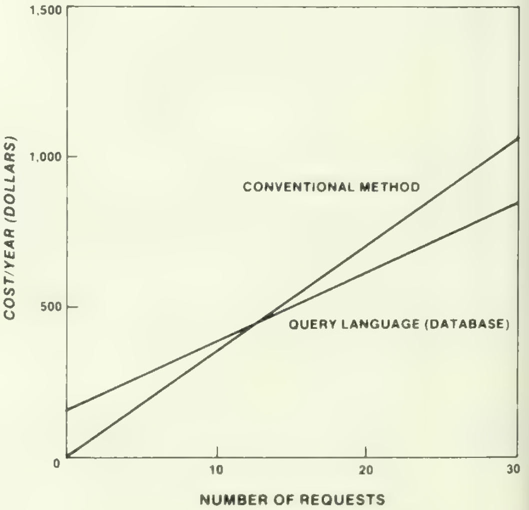


Figure 3.—*Cost comparisons for simple queries, M nesota Aspen-Birch Unit, 1977 data.*

---

[6] *The estimate was made by the research forester performing the query.*

report can be written in 1 day with Report Writer. The processing cost for the present method is about $5.00 per table, based on example tables. The Report Writer costs averaged $10.00 per table for 18 relatively complex reports. Figure 4 compares conventional costs with database costs for a varying number of requests for special tables. The break-even point is about three requests per year. After that, the database becomes more cost-effective.

Tree Detail Database

Description

The tree detail database had a two-level hierarchical data structure similar to that of the plot summary database. The first level contains the same plot attributes as the plot summary database; the second level contains individual tree attributes instead of species group summaries (fig. 5). The relation between the two entities is one-to-many; that is, the lower level entity is repeated for a plot as many times as there are trees measured for that plot.

Use

The tree-detail database can be used to prepare the same formal summary reports for a survey unit or other area as those produced from the plot summary database, but test runs indicate that the cost may be 10 times higher. The size and complexity of the tree-detail database make it an inefficient means of writing such summary reports. The plot summary database provides this capability more efficiently.

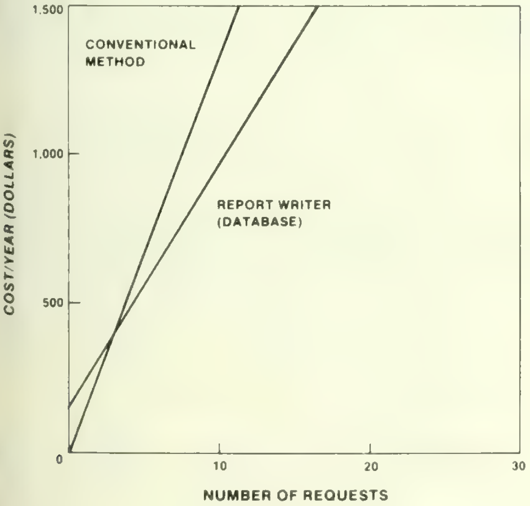


Figure 4.—*Cost comparisons for summary reports, Minnesota Aspen-Birch Unit, 1977 data.*

Some information requests may require retrieval of individual tree detail. Examples include providing input tree lists for tree growth projection systems (Leary *et al.* 1977) and producing special summaries of information not contained in the plot summary database. To meet these needs a tree-detail database can be developed.

Costs

The direct computing costs for establishing and operating a tree-detail database for Minnesota's Aspen-Birch Unit were:

Initial costs:	
Definition	$ 2.50
Creation	
Load	330.00
Index	620.00
Archive	25.00
Total	$977.50

Operating costs:	
Daily disk storage	20.00
Copy from tape to disk	7.00
Release (purge files)	.05
Retrievals and reports	variable

Point number
Tree number
Tree history
Species
D.b.h.
D.b.h. increment
Bole length
Bole length top diameter outside bark
Cull cubic feet
Saw log length
Saw log top diameter outside bark
Cull board feet
Log grade
Surface defect
Internal defect
Relative bole length
Crown ratio
Crown class
Damage cause of death
Tree cover class
Two inch D.b.h. class
Tree size class
Softwood hardwood species group code
Species group
Point occupancy
Ingrowth code
Stocking size class
Stocking percent
D.b.h. last measurement
Trees/acre
Net cubic foot vol/acre
Net cubic foot saw log vol/acre
Net board foot vol/acre
Annual cubic-foot growth/acre
Annual board-foot growth/acre
Annual cubic-foot mortality/acre
Annual board-foot mortality/acre
Basal area/tree/acre
Green tons of bole/acre
Green tons of top/acre

Figure 5.—*Individual tree data for tree detail database.*

This tree-detail database included 4,907 plots and 24.5 million characters.

Costs of disk storage and copying the backup tape to disk are higher here than for the plot summary database due to the increase in the total number of characters for the database.

Evaluation of Alternatives

To evaluate the usefulness of the tree-detail database, two types of requests requiring tree detail data were examined: developing tree lists for input to a tree growth projection system, and developing resource information that requires individual tree records.

Three alternatives for providing input tree lists for a tree growth processor were compared:

1. Using the present method of reading the entire file of tree detail information stored as a packed binary sequential file.
2. Using a tree-detail database to create an intermediate file from which the tree growth processor will subsequently read.
3. Using a plot summary database for selecting plots based on requested characteristics (e.g., red pine plots with basal area greater than 120 sq ft/acre), and creating a file of the selected plot numbers. The file of plot numbers is used to read the tree data from a modified format for the present sequential tree file.

The costs for the three alternatives are presented in table 3. The cost of reading the sequential file makes the present method expensive for repeated runs. The tree-detail database is less expensive. However, the plot summary database used in conjunction with an unformatted binary sequential file of tree detail data is cheaper still. For more than two requests per year, alternative three (the summary database used with a modified tree file) is the m economical method (fig. 6).

It is difficult to predict the variety of requests tree detail information for research purposes. T potential of the database for research is just begi ning to be explored. However, to provide some idea the cost, a recent request will serve as an examp

A scientist was interested in obtaining informati on tree distribution by diameter class for red pi plots within a specified range of site index valu The database was used first to obtain a list of pl numbers meeting the selection criteria; subs quently, a Report Writer command file was execut for individual plots from the list of selected pl numbers. The command file created an intermedia file which summarized the number of trees by 2-in diameter classes. The intermediate file provided i put to an applications program, which created histogram (fig. 7). The entire sequence was pe formed without the user writing a program. The ste were repeated several times for different plots. Eac histogram cost approximately $2.00.

CONCLUSIONS

Plot Summary Database

For both queries and reports, the System 20 database management system had advantages ov the processing of a sequential plot summary file. Th savings in personnel time alone paid for the costs database establishment. In addition, the softwa provided previously unavailable reporting capabil ties and access to users. The plot summary databa approach is a viable alternative for processing speci requests and should be evaluated on a region-wi basis.

Table 3.—*Cost comparison of three alternatives for providing tree growth processor input*
(Dollars)

Activity	Present method; packed sequential file	Tree detail database	Plot summary database & modified tree rate
Programming	8.00	4.00	4.00
Computer time (create and read file)	120.00	33.00	26.00
Copy & storage (assume 1 hr storage)	—	8.00	3.30
Total	128.00	45.00	33.30
Fixed cost of database creation	—	975.00	150.00[1]

[1] Includes costs of additional tapes and their storage for the modified sequential files of tree detail data.

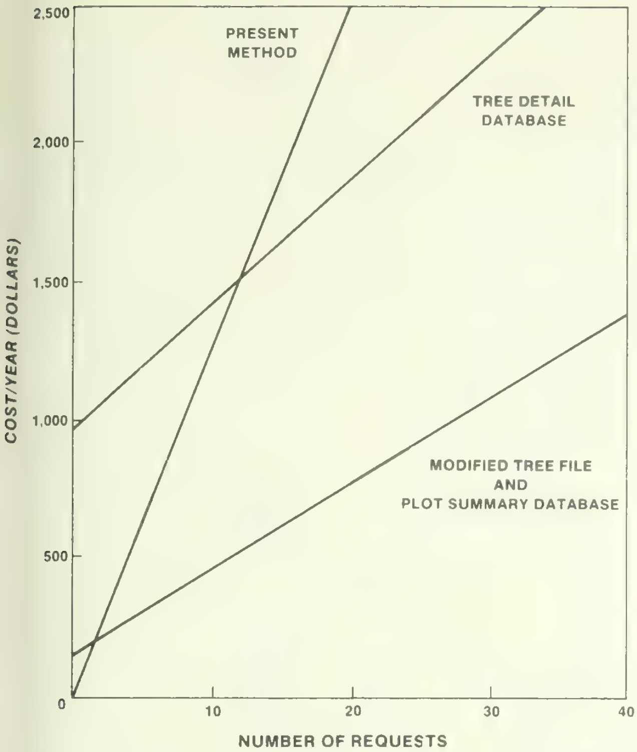


Figure 6.—*Cost comparisons of creating tree growth processor input files, Minnesota Aspen-Birch Unit, 1977 data.*

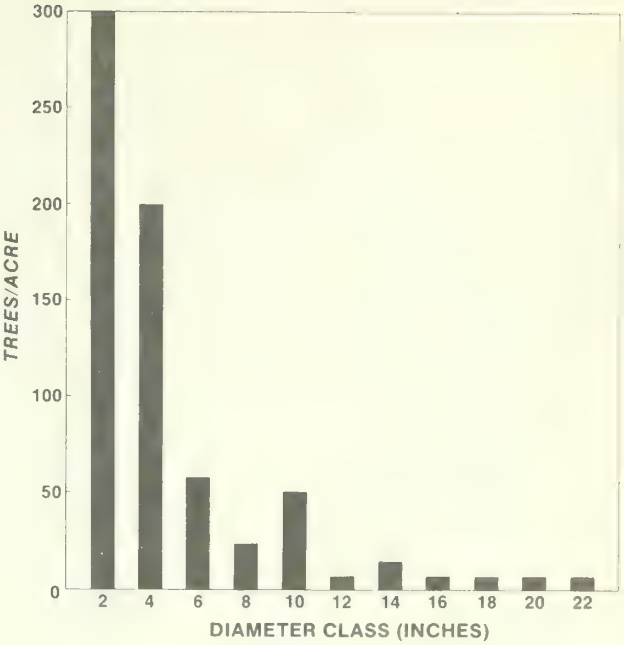


Figure 7.—*Trees/acre by 2-inch diameter class for a sample inventory plot, Minnesota Aspen-Birch Unit, 1977.*

Tree Detail Database

The tree detail database is not appropriate for unit-wide summary reports, nor is it cost-effective for creating intermediate files to be used as input to application programs. The real potential for the tree detail database lies in research applications, but additional experience will be needed to determine the cost-effectiveness. Very likely, the increased accessibility of the survey data will justify the cost of creating a tree detail database for work units that have specific research assignments.

As these database management system applications are implemented, however, it is important that the sampling error of retrieval data be evaluated. Studies are now underway to do this. Subsequent reports will also deal with the interface of the database management system with the tree growth processor to update past inventory data.

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Murphy, Dennis L. 1981. Database management: a forest inventory application. U.S. Department of Agriculture Forest Service, General Technical Report NC-67, 9 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Describes the design and creation of two databases using data from a unit of the fourth Minnesota Forest Inventory, and analyzes the cost-effectiveness of each.

KEY WORDS: data processing, break-even analysis, cost-effectiveness, logical database design, schema diagram.

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North Central
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General Technical
Report NC-68

Guide to Bird Habitats of the Ozark Plateau

Keith E. Evans and Roger A. Kirkman

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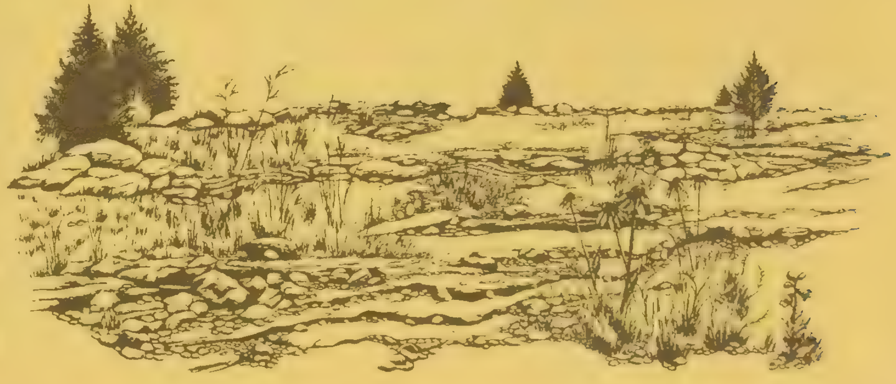

GUIDE TO BIRD HABITATS OF THE OZARK PLATEAU

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FOREWORD

The Ozark Plateau is becoming increasingly important to both urban and rural inhabitants by providing bird-watching, photography, hiking, canoeing, sightseeing, hunting, and fishing. Visitors who come to enjoy wildlife other than by hunting accounted for 200,000 visitor days of use in 1975 on the Mark Twain National Forest; the projected demand for 1990 is 550,000 visitor days.

People interested in wildlife are attracted to the Ozark Plateau because of the extensive forests and glades, and the diverse environments for wildlife found there. One of the reasons why the wildlife community of the Ozark Plateau is so diverse is the geological history of this hill country. Aside from the Appalachians and the Mexican Plateau, this is the only area of the North American mainland to escape both flooding and glaciation since its emergence some 500 million years ago. Some of the plants and animals living here have been evolving without interruption since that time.

Another reason the Ozark wildlife community is so diverse is that the Ozarks are a focal point of several converging plant communities. Here, eastern hardwoods, southern pines, and western prairies, along with the wildlife each supports, all reach the outward limits of their advance. As a result, plant and animal representatives of different environmental conditions are found in close proximity.

INTRODUCTION

People who are interested in birds are of all ages and from all walks of life. Their interest in birds goes through several stages — *awareness, desire to identify*, and *interest in bird biology*. No reference book is needed for awareness — the great diversity in bird behavior, size, color, and song perpetuates awareness. Many reference books are already available to assist in identification. (The two most popular are *Peterson's Field Guide*[1] from Houghton Mifflin and *Birds of North America* from Golden Press.) Bird biology, especially habitat selection, is what the present reference book is about.

This guide illustrates 26 habitats occurring in the Ozarks. Some of these are very limited, but are included for completeness. We have listed the bird species associated with each of these habitats, and have included season of residency, abundance, and expected activity for each bird in each habitat. Species that only migrate through have been omitted because they only stop for a short time and generally do not select particular habitats.

Although this reference was written specifically for the Ozark Plateau, many of these same habitats and associated birds are found throughout most of the eastern United States. So with due regard for local differences, birders will find this reference generally useful all over the eastern part of the nation.

Almost any landscape has bird species that have adapted to inhabit it. Whenever a landscape is altered, some species will prosper, others will suffer. Land managers can use this book to predict which species will benefit and which will decline when tree and shrub cover is changed.

The habitat grouping or classification in this work should bring some order out of the diversity of bird habitats in the Ozark Plateau. Used as a standard, this habitat grouping will help birders, forest users, and forest managers communicate more precisely.

HOW TO USE THIS BOOK

This book is designed to be used in two ways: (1) to determine the habitats of a specific bird, and (2) to determine what birds to expect in a specific habitat.

To determine the habitats of a specific bird, turn to the locator table on page 69. Find the desired bird in the left-hand column, the "x's" then show the habitats it prefers. Turn to these habitats for details on residency, abundance, nesting, and foraging from the charts. (The charts are explained on page VI.)

To determine what birds to expect when you are birding in a specific habitat, turn to the list of habitats and habitat groups on page VI and pick out the appropriate habitat. Look at the illustration to see if it matches the habitat you are in. The charts list the birds found in that habitat.

---

[1] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

HABITATS AND HABITAT GROUPS

Following is a list of 7 habitat groups that are broken down into the 26 habitats illustrated and charted in this publication.

00.— Grass or Crop
- 01 Cereal Grain (Annual Crop)
- 02 Annuals
- 03 Legumes (Perennial Crop)
- 04 Perennial Grass (Cool Season)
- 05 Perennial Grass (Warm Season)
- 06 Shrub and Grass

10.— Brush
- 11 Shrub and Fruiting Tree
- 12 Grass and Shrub Savannah
- 13 Shrub and Fruiting Tree Savannah
- 14 Forest and Field Edge
- 15 Glades
- 16 Eastern Redcedar

20.— Oak-Hickory Forest
- 21 Oak-Hickory Regeneration (Herbaceous Stage)
- 22 Oak-Hickory Regeneration (Shrub-Seedling Stage, stems less than 3 inches in diameter)
- 23 Immature Oak-Hickory (Poles and Sapling, 3 to 9 inches in diameter)
- 24 Mature Oak-Hickory (Open Undergrowth)
- 25 Mature Oak-Hickory (Dense Undergrowth)
- 26 Old-Growth Oak-Hickory

30.— Shortleaf Pine Forest
- 31 Shortleaf Pine Reproduction (0 to 3 inches in diameter)
- 32 Immature Shortleaf Pine (3 to 9 inches in diameter)
- 33 Mature Shortleaf Pine (9 + inches in diameter)
- 34 Old-Growth Shortleaf Pine

40.— Wetland
- 41 Wooded Streamside and Bottomland Hardwoods
- 42 Waterhole

50.— Other
- 51 Limestone Bluff and Cave
- 52 Farmyard or Town Residence

EXPLANATION OF HABITAT CHARTS

Residence

The first letter is the residence status:

R = Permanent resident
S = Summer or breeding resident
W = Winter resident

Abundance

The second letter is the expected abundance in each habitat where the bird is likely to occur:

A = Abundant
B = Moderately abundant
C = Common
D = Uncommon
E = Extremely rare or endangered

Foraging and Nesting Levels

Habitats were divided into six levels to designate where each bird forages and nests. These levels are generalized; for specifics and for birds that are exceptions, a clarifying note is given. The six levels are:

WATER = Stream or lake
HERB = Ground and herbaceous cover less than 1 meter tall
SHRUB = Shrub and shade tolerant midstory level.
TREE = Tree crown level.
BARK = The surface of both living and dead tree trunks and limbs.
AIR = Aerial feeders

Primary Foods

The food habitats of birds are often variable, depending on season and availability. We have included four broad categories of food:

SEEDS = Seeds, fruits, buds, or other vegetable matter
BUGS = Insects and other invertebrates
PREY = Vertebrate prey
OTHER = Carrion and other

HABITATS

01 — CEREAL GRAIN (ANNUAL CROP) — Annually planted, domestic, high energy grains such as wheat, milo (grain sorghum), and corn. Normally planted as a single species.

Much bare ground. Generally very uniform horizontally and vertically; little diversity.

01 CEREAL GRAIN (Annual Crop)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Canada Goose	W	D		F								●	
Mallard	W	D		F					●				
Turkey Vulture	S	C		F								●	
Black Vulture	S	E		F								●	
Red-tailed Hawk	R	C		F							●		
Rough-legged Hawk	W	D		F							●		
Golden Eagle	W	D		F							●		
Marsh Hawk	W	D		F							●		
American Kestrel	R	C		F				F		●	●		
Bobwhite	W	C		F					●				
Killdeer	S	C		X						●			Rare in winter
Rock Dove	R	C		F					●				
Mourning Dove	R	C		F					●				
Eastern Kingbird	S	C						F		●			
Horned Lark	R	D		X					●	●			
Rough-winged Swallow	S	C						F		●			
Barn Swallow	S	C						F		●			
Cliff Swallow	S	D						F		●			
Purple Martin	S	C						F		●			
Common Crow	R	B		F								●	

---

[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

01 CEREAL GRAIN (Annual Crop)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Eastern Meadowlark	R	C		F					●	●			
Red-winged Blackbird	R	B		F					●	●			
Brewer's Blackbird	W	D		F					●				
Common Grackle	R	C		F					●				
Indigo Bunting	S	C		F					●				Only next to edge
Dickcissel	S	C		F						●			
Savannah Sparrow	W	D		F					●				
Dark-eyed Junco	W	A		F					●				Only next to edge
Tree Sparrow	W	C		F					●				Only next to edge
White-crowned Sparrow	W	D		F					●				Near weeds and brush
Fox Sparrow	W	D		F					●				Near weeds and brush
Song Sparrow	W	D		F					●				Near weeds and brush

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[1] Residence Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N) Both Forage and Nest in same level (X)

02 — ANNUALS — Mostly annual plants the first year after soil disburbance. Disking, plowing, or both commonly lead to the occurrence of annual plants.

Composition varies from a single species (such as a solid stand of ragweed) to a mixture of such species as ragweed, foxtail, croton, smartweed, lespedeza, morning glory, wild carrot, and sunflower.

02 ANNUALS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		F								●	
Red-tailed Hawk	R	C		F							●		
Rough-legged Hawk	W	D		F							●		
American Kestrel	R	C		F				F		●	●		
Bobwhite	R	C		F					●				
Killdeer	S	C		X						●			Grazed or bare ground areas
Mourning Dove	R	C		F					●				
Eastern Kingbird	S	C						F		●			
Horned Lark	R	C		X					●	●			
Rough-winged Swallow	S	C						F		●			
Barn Swallow	S	C						F		●			
Cliff Swallow	S	D						F		●			
Purple Martin	S	D						F		●			
Common Crow	R	C		F								●	
Eastern Meadowlark	R	C		F					●	●			May occasionally nest
Red-winged Blackbird	R	B		F					●	●			May occasionally nest
Brewer's Blackbird	W	D		F					●				
Common Grackle	R	C		F					●				
Dickcissel	S	C		F						●			May occasionally nest
American Goldfinch	R	C		X					●	●			

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extreme, Rare, or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same area (X)

02 ANNUALS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Lark Sparrow	S	C		X					●	●			
Dark-eyed Junco	W	A		F					●				
Tree Sparrow	W	C		F					●				
Harris Sparrow	W	D		F					●				
White-crowned Sparrow	W	D		F					●				Near brush
White-throated Sparrow	W	D		F					●				Near brush
Fox Sparrow	W	D		F					●				Near brush
Swamp Sparrow	W	D		F					●				Low wet areas
Song Sparrow	R	D		X					●	●			

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extreme, Rare, or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same area (X)

03 — LEGUMES (PERENNIAL CROP) — Bare ground openings in woods or brush have been seeded with a single or mixed species of introduced legumes. Species commonly used are red clover, ladino clover, bird's foot trefoil, and Korean lespedeza.

03 LEGUMES (Perennial Crop)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		F								●	
Red-tailed Hawk	R	C		F							●		
Rough-legged Hawk	W	D		F							●		
American Kestrel	R	C		F				F		●	●		
Bobwhite	R	C		X					●	●			
Turkey	R	C		F					●	●			May nest near edge
Mourning Dove	R	C		F					●				
Ruby-throated Hummingbird	S	C		F								●	
Eastern Kingbird	S	C						F		●			
Scissor-tailed Flycatcher	S	D						F		●			
Horned Lark	R	C		X					●	●			Grazed areas
Rough-winged Swallow	S	C						F		●			
Barn Swallow	S	C						F		●			
Cliff Swallow	S	D						F		●			
Purple Martin	S	D						F		●			Near farmyards
Common Crow	R	C		F								●	
Eastern Meadowlark	R	C		X					●	●			
Red-winged Blackbird	R	B		F					●	●			Occasionally nests
Rusty Blackbird	W	D		F					●				
Brewer's Blackbird	W	D		F					●				

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest [illegible]

03 LEGUMES (Perennial Crop)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Common Grackle	R	C		F					●				
Dickcissel	S	B		X						●			
American Goldfinch	R	C		X					●	●			
Savannah Sparrow	W	C		F					●				
Grasshopper Sparrow	S	D		X						●			
Lark Sparrow	S	D		F					●	●			Grazed areas
White-crowned Sparrow	W	D		F					●				Near brush
White-throated Sparrow	W	D		F					●				Near brush
Fox Sparrow	W	D		F					●				Near brush
Swamp Sparrow	W	D		F					●				Near brush, low wet areas
Song Sparrow	R	D		X					●	●			Near brush

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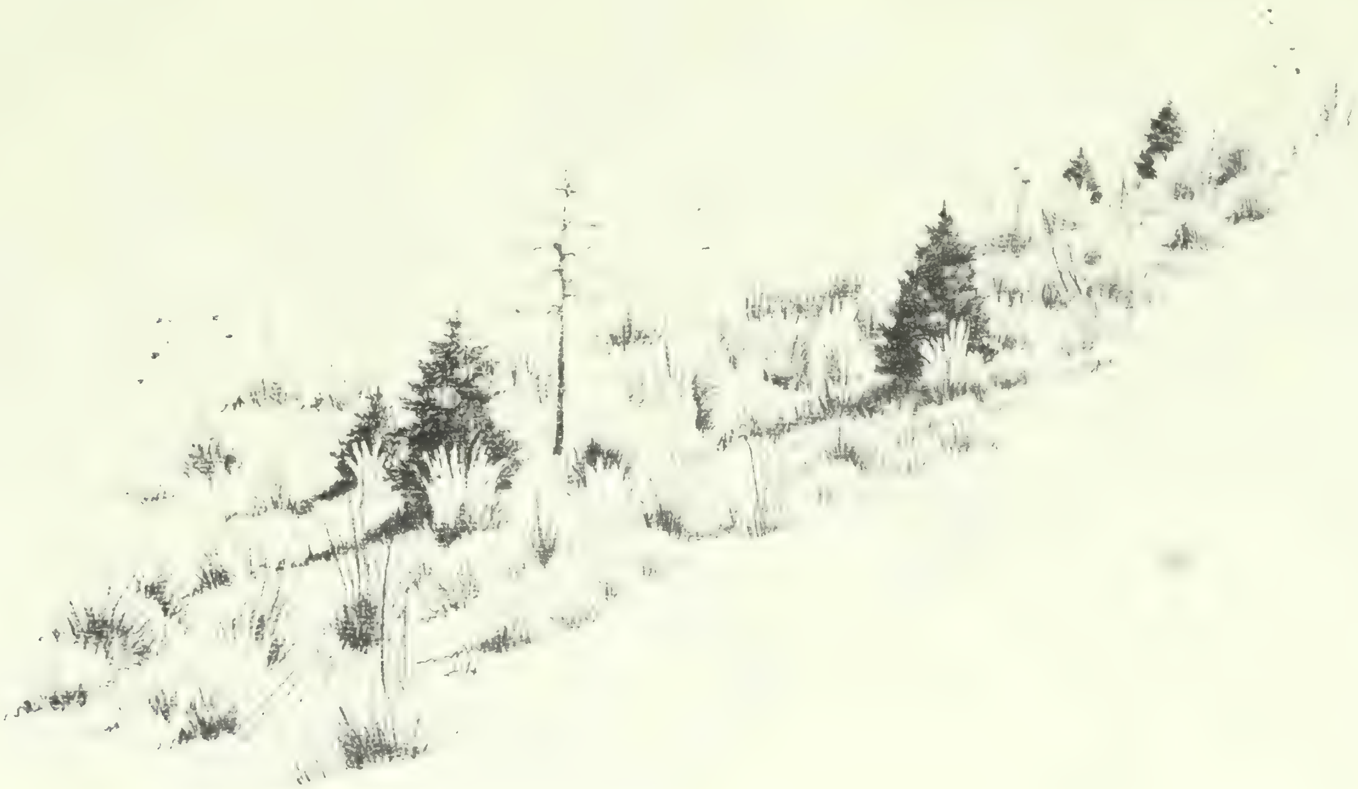
[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest [illegible]



04 — PERENNIAL GRASS (COOL SEASON) — Consists of pasture grasses such as bluegrass, fescue, and purpletop. Forbs, including legumes, make up less than 20 percent of total. Woody plants occupy less than 10 percent of space.

Forms a continuous sod that eliminates bare ground; very little diversity in height.

04 PERENNIAL GRASS (Cool Season)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Canada Goose	W	D		F								●	
Turkey Vulture	S	C		F								●	
Black Vulture	S	D		F								●	
Red tailed Hawk	R	C		F							●		
Rough legged Hawk	W	D		F							●		
Marsh Hawk	R	C		F							●		
American Kestrel	R	C		F				F		●	●		
Bobwhite	R	D		X					●	●			
Killdeer	S	C		X						●			Grazed areas, rare in winter
Upland Sandpiper	S	D		X						●			Hay meadows
Mourning Dove	R	C		F					●				
Eastern Kingbird	S	C						F		●			
Scissor tailed Flycatcher	S	D						F		●			
Horned Lark	R	C		X					●	●			Grazed areas
Rough winged Swallow	S	C						F		●			
Barn Swallow	S	C						F		●			
Cliff Swallow	S	D						F		●			
Purple Martin	S	C						F		●			Near towns and farmyards
Common Crow	R	C		F								●	
Eastern Meadowlark	R	C		X					●	●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

04 PERENNIAL GRASS (Cool Season)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Red-winged Blackbird	R	B		X					●	●			Often nests near water
Brown-headed Cowbird	R	C		X						●			Parasitic nester
Dickcissel	S	C		X						●			
American Goldfinch	R	C		X					●	●			
Grasshopper Sparrow	S	C		X						●			Hay fields with song perches
Lark Sparrow	S	D		X					●	●			Grazed areas
Dark eyed Junco	W	A		F					●				Edge
White crowned Sparrow	W	D		F					●				Near brush
White throated Sparrow	W	D		F					●				Near brush
Fox Sparrow	W	D		F					●				Near brush
Swamp Sparrow	W	D		F					●				Near brush
Song Sparrow	R	D		X					●	●			Near brush

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

05 — PERENNIAL GRASS (WARM SEASON) — Consists of grasses and forbs that are native to the tall grass prairie. The primary grasses include big bluestem, little bluestem, indian grass, and switchgrass with lesser amounts of prairie dropseed and side oats grama. Usually mixed, but colonies of single species — such as a solid stand of little bluestem — are not uncommon.

Forbs vary to include such species as lead plant, blazing star (gayfeather), coneflowers, sunflowers, black-eyed susan, rattlesnake master, wild indigo, prairie clovers, wild strawberry, and desmodium.

Woody plants normally cover less than 10 percent of the area. Sumac, plum, persimmon, dogwood, cedar, oak, and elm are common woody invaders in the absence of fire.

Very diverse vertically. Clumps or bunches form a high canopy over bare soil in between.

05 PERENNIAL GRASS (Warm Season)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		F								●	
Black Vulture	S	D		F								●	
Red-tailed Hawk	R	C		F							●		
Rough-legged Hawk	W	D		F							●		
Golden Eagle	W	E		F							●		
Marsh Hawk	R	C		X							●		Prefers this habitat
American Kestrel	R	C		F							●		
Greater Prairie Chicken	R	E		X					●	●			Large prairies only
Bobwhite	R	C		X					●	●			
Turkey	R	D		X					●	●			
Killdeer	S	C		X						●			Grazed areas
Upland Sandpiper	S	D		X						●			
Mourning Dove	R	C		F					●				Burned or grazed areas
Short-eared Owl	W	D		F							●		
Eastern Kingbird	S	C						F		●			
Scissor-tailed Flycatcher	S	D						F		●			
Horned Lark	R	C		X					●	●			Grazed areas
Rough-winged Swallow	S	C						F		●			
Barn Swallow	S	C						F		●			
Cliff Swallow	S	D						F		●			

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

05 PERENNIAL GRASS (Warm Season)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Purple Martin	S	C						F		●			
Common Crow	R	C		F								●	
Eastern Meadowlark	R	B		X					●	●			
Red-winged Blackbird	R	B		X					●	●			
Brown-headed Cowbird	R	C		X					●	●			Parasitic nester
Dickcissel	S	C		X						●			
American Goldfinch	R	C		X					●	●			
Savannah Sparrow	W	D		F					●				
Grasshopper Sparrow	S	C		X						●			Hay fields
Lark Sparrow	S	C		X					●	●			Grazed
Dark eyed Junco	W	A		F					●				Edge
White-crowned Sparrow	W	C		F					●				Near brush
White-throated Sparrow	W	C		F					●				Near brush
Fox Sparrow	W	D		F					●				Near brush
Swamp Sparrow	W	D		F					●	●			Near brush, wet areas
Song Sparrow	R	D		X					●	●			Near brush

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

06 — SHRUB AND GRASS — Represents early stages of plant succession in old fields. Sumac, persimmon, sassafras, plum, black cherry, blackberry, corralberry, cedar, oak, and hickory are the predominant woody vegetation.

Herbaceous plants include aster, golden rod, wild carrot, cinquefoil, yarrow, ragweed, fleabane, and lettuce.

Grasses include broomsedge, bluegrass, purpletop, poverty-oat grass, panic grass, and occasionally indian grass and big bluestem.

06 SHRUB AND GRASS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		F								●	
Red tailed Hawk	R	C		F							●		
Marsh Hawk	R	C		X							●		
American Kestrel	R	C		F							●		
Bobwhite	R	C		X					●	●			
American Woodcock	S	C		X						●			
Mourning Dove	R	C		F					●	●			May nest in cedars
Short-eared Owl	W	D		F							●		
Ruby throated Hummingbird	S	C		F	F							●	May occasionally nest
Rough-winged Swallow	S	C						F		●			
Barn Swallow	S	C						F		●			
Cliff Swallow	S	D						F		●			
Purple Martin	S	D						F		●			
House Wren	S	C		F						●			
Bewick's Wren	S	D		F						●			
Carolina Wren	R	D		F						●			
Brown Thrasher	S	C		F	N				●	●			
Loggerhead Shrike	R	C		F	X					●	●		
White eyed Vireo	S	C			X					●			
Bell's Vireo	S	D			X					●			
Yellow rumped Warbler	W	D		F					●	●			
Common Yellowthroat	S	C		N	F					●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest at same level (X)

06 SHRUB AND GRASS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Yellow-breasted Chat	S	C		F	X					●			
Eastern Meadowlark	R	C		X					●	●			Large grassy areas preferred
Rusty Blackbird	W	D		F					●				
Brewer's Blackbird	W	D		F					●				
Brown headed Cowbird	R	C		X	N				●	●			Parasitic nester
Cardinal	R	B		F	X				●				
Blue Grosbeak	S	C			X				●				
Indigo Bunting	S	C		F	N				●				Edge
Dickcissel	S	C		X	X				●	●			
American Goldfinch	R	C		X					●	●			
Rufous-sided Towhee	R	B		F	X				●	●			
Savannah Sparrow	W	D		F					●				
Bachman's Sparrow	S	E		X	F				●	●			Prefers dense grass
Dark-eyed Junco	W	A		F					●				Edge
Tree Sparrow	W	C		X					●				
Field Sparrow	R	C		X	F				●	●			Abundant in summer
White-crowned Sparrow	W	C		F					●				
White throated Sparrow	W	C		F					●				
Fox Sparrow	W	D		F					●				
Swamp Sparrow	W	C		F					●	●			Near streams
Song Sparrow	W	C		F					●	●			Near streams

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest at same level (X)

11 — SHRUB AND FRUITING TREE — An opening that has partly grown up in "pioneer" trees — those first to seed in an opening. Commonly found are stands of sapling and pole-size sassafras, persimmon, plum, black cherry, hickory, and cedar trees and clones of shrubs such as sumac, coral berry, and blackberry. Grasses (panic grass, cheat, broomsedge, and bluegrass) and few forbs are still present in the spaces among the trees and shrubs.

11 SHRUB AND FRUITING TREE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Red tailed Hawk	R	D		F							●		
Bobwhite	R	B		X					●	●			
American Woodcock	S	C		X						●			Wet areas
Mourning Dove	R	C		F		N			●	●			
Yellow-billed Cuckoo	S	C			X	F				●			
Black billed Cuckoo	S	E			X	F				●			
Ruby throated Hummingbird	S	C		F	F	N						●	
Common Flicker	R	C		F		N				●			Cavity excavator
Red headed Woodpecker	R	C				N	F			●			Cavity excavator
Hairy Woodpecker	R	D					F			●			
Downy Woodpecker	R	D				N	F			●			Cavity excavator
Eastern Kingbird	S	B				N		F		●			
Scissor tailed Flycatcher	S	D				N		F		●			
Blue Jay	R	C			F	F				●			Occasional nester
Carolina Chickadee	R	D			F	X	F			●			Cavity user
House Wren	S	D		F	X					●			Cavity user
Bewick's Wren	S	D		F	X					●			
Carolina Wren	R	D		F	X					●			Cavity user
Mockingbird	R	C			X					●			
Gray Catbird	S	C			X					●			

[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A), Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

11 SHRUB AND FRUITING TREE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Brown Thrasher	R	C		F	X					●			Rare in winter
Blue-gray Gnatcatcher	S	C			X	X				●			
Cedar Waxwing	R	D			F	X			●				
White-eyed Vireo	S	C			X					●			
Bell's Vireo	S	D			X					●			
Black-and-white Warbler	S	C		N			F			●			
Blue-winged Warbler	S	C		N	F	F				●			
Yellow Warbler	S	D			N	F				●			
Yellow-rumped Warbler	W	C		F					●	●			
Prairie Warbler	S	D			X	X				●			
Common Yellowthroat	S	C		N	F					●			
Yellow-breasted Chat	S	C		F	X					●			
Orchard Oriole	S	C				X				●			
Rusty Blackbird	W	D		F					●				
Brewer's Blackbird	W	D		F					●				
Brown-headed Cowbird	R	B		F	N	N			●	●			Parasitic nester
Cardinal	R	B		F	X				●				
Blue Grosbeak	S	B			X				●				
Indigo Bunting	S	B		F	N				●				Edge
Painted Bunting	S	E		F	X				●	●			Extreme southern Missouri

[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

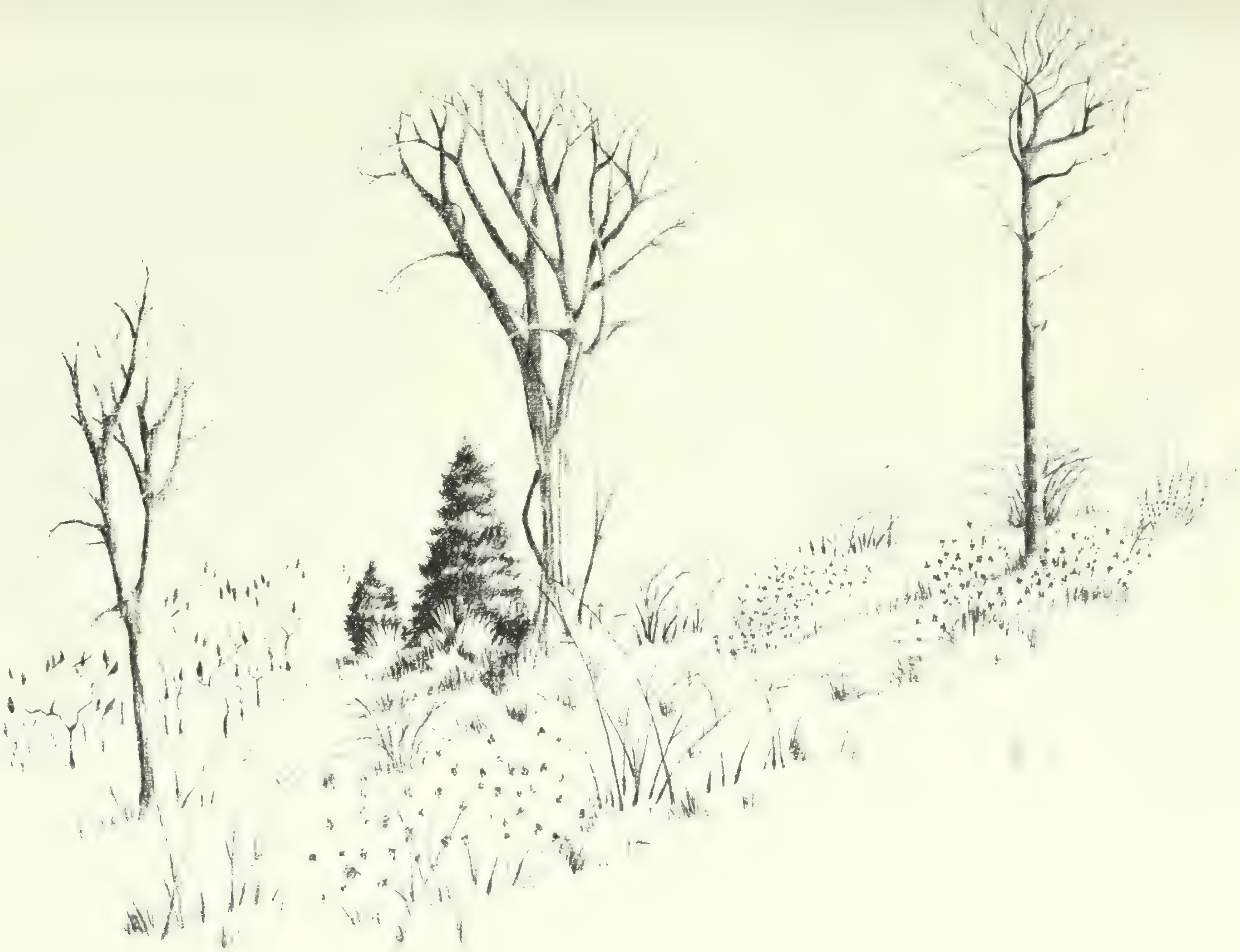
11 SHRUB AND FRUITING TREE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Evening Grosbeak	W	D			F	F			●				
Purple Finch	W	D				F			●				
Pine Siskin	W	C			F	F			●				
American Goldfinch	R	C		X					●	●			
Rufous-sided Towhee	R	B			X				●	●			
Tree Sparrow	W	C		F					●				
Field Sparrow	R	C		X	F				●	●			Abundant in summer
Harris Sparrow	W	D		F					●				
White-crowned Sparrow	W	C		F					●				
White-throated Sparrow	W	C		F					●				
Fox Sparrow	W	D		F					●				
Swamp Sparrow	W	D		F					●	●			
Song Sparrow	R	D		X					●	●			Mostly winter

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E

[3] Forage (F), Nest (N), Both Forage and Nest at same level (X



12 — GRASS AND SHRUB SAVANNAH — A "parklike" area with scattered or clumped immature trees and a grassy ground cover. Found on dryish sites such as benches, upland ridges, and south and west slopes.

12 GRASS AND SHRUB SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		F		N						●	Nest in large cavity
Black Vulture	S	B		F								●	
Sharp-shinned Hawk	R	D		F				F			●		
Cooper's Hawk	R	D		F				F			●		
Red-tailed Hawk	R	C		F		N					●		
American Kestrel	R	C		F		N				●	●		Cavity user
Bobwhite	R	B		X					●	●			
Mourning Dove	R	B		F		N			●	●			
Yellow-billed Cuckoo	S	C			X	F				●			
Black-billed Cuckoo	S	D			X	F				●			
Barred Owl	R	D		F		N					●		Cavity user
Ruby-throated Hummingbird	S	C		F	F	N						●	
Common Flicker	R	C		F		N				●			Cavity excavator
Red bellied Woodpecker	R	C				N	F			●			Cavity excavator
Red headed Woodpecker	R	C				N	F			●			Cavity excavator
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Eastern Kingbird	S	B				N		F		●			
Scissor tailed Flycatcher	S	D				N		F		●			
Eastern Phoebe	S	C						F		●			Nest on beams of old buildings

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

12 GRASS AND SHRUB SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	C		F	F	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	C			F	X	F			●			Cavity user
Tufted Titmouse	R	C			F	X				●			Cavity user
White-breasted Nuthatch	R	D				N	F			●			Cavity user
House Wren	S	C		F	X					●			Cavity user
Bewick's Wren	S	D		F	X					●			
Carolina Wren	R	D		F	X					●			Cavity user
Mockingbird	R	C			X					●			
Gray Catbird	S	C			X					●			
Brown Thrasher	R	C			X					●			Rare in winter
American Robin	R	C		F		N				●			
Eastern Bluebird	R	C		F	F	N				●			Cavity user
Blue-gray Gnatcatcher	S	C			X	X				●			
Loggerhead Shrike	R	C		F	X					●	●		
White-eyed Vireo	S	C			X					●			
Yellow throated Vireo	S	D			X					●			
Black-and-white Warbler	S	C		N			F			●			
Yellow-rumped Warbler	W	C		F					●	●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

12 GRASS AND SHRUB SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Prairie Warbler	S	C			X					●			
Yellow breasted Chat	S	C		F	X					●			
Eastern Meadowlark	R	D		X					●	●			Prefers less woody cover
Northern Oriole	S	C			X	X				●			Prefers park-like area
Rusty Blackbird	W	D		F					●				
Brewer's Blackbird	W	D		F					●				
Common Grackle	R	B		F	N				●				
Brown-headed Cowbird	R	B		F	N	N			●	●			Parasitic nester
Cardinal	R	B		F	X				●				
Blue Grosbeak	S	B			X				●				
Indigo Bunting	S	B		F	N				●				
Dickcissel	S	C		X						●			
Purple Finch	W	D				F			●				
American Goldfinch	R	C		X					●	●			
Rufous sided Towhee	R	B			X				●	●			Rare in winter
Bachman's Sparrow	S	E		X	F				●	●			
Tree Sparrow	W	C		F					●				
Chipping Sparrow	S	B		F	N				●	●			
Field Sparrow	R	B		X	F				●	●			Rare in winter
White crowned Sparrow	W	D		F					●				

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

12 GRASS AND SHRUB SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
White-throated Sparrow	W	D		F					●				
Fox Sparrow	W	D		F					●				
Swamp Sparrow	W	D		F					●	●			
Song Sparrow	R	D		X					●	●			Mostly winter

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

13 — SHRUB AND FRUITING TREE SAVANNAH — Scattered trees over a dense shrub understory growing on wet sites.

Trees over 15 feet high cover 10 to 50 percent of area overhead. Trees on uplands include various oaks and hickories; on lowlands walnut, maple, and elm.

Underbrush is diverse, including blackberry, dogwood, hazel, black haw, indian cherry, ironwood, redbud, buckeye, hawthorne, fragrant sumac, smooth sumac, hazelnut, greenbriar, and corralberry.

Grasses are few or non-existent, but forbs include aster, tick trefoil, wood mint, avens, sunflower, lespedeza, lettuce, and sensitive-briar.

13 SHRUB AND FRUITING TREE SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Sharp-shinned Hawk	R	D		F							●		
Cooper's Hawk	R	D		F							●		
Red-tailed Hawk	R	C		F		N					●		
American Kestrel	R	C		F		N				●	●		Cavity nester
Ruffed Grouse	R	E		X					●	●			
Bobwhite	R	B		X					●	●			
Turkey	R	D		X					●	●			
Mourning Dove	R	C		F		N			●	●			
Yellow-billed Cuckoo	S	C			X	F				●			
Black-billed Cuckoo	S	F			X	F				●			
Whip-poor-will	S	C		N				F		●			
Ruby-throated Hummingbird	S	C		F	F	N						●	
Common Flicker	R	C		F		N				●			Cavity excavator
Pileated Woodpecker	R	E				N	F			●			Cavity excavator (large snag)
Red-bellied Woodpecker	R	C				N	F			●			Cavity excavator
Red-headed Woodpecker	R	C				N	F			●			Cavity excavator
Yellow-bellied Sapsucker	W	C					F					●	
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Eastern Kingbird	S	B				N		F		●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

13 SHRUB AND FRUITING TREE SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Eastern Phoebe	S	C						F		●			Nest on beams of old buildings
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	B		F	F	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	C			F	X	F			●			Cavity user
Tufted Titmouse	R	C			F	X				●			Cavity user
White-breasted Nuthatch	R	D				N	F			●			Cavity user
House Wren	S	D		F	X					●			Cavity user
Bewick's Wren	S	D		F	X					●			
Carolina Wren	R	D		F	X					●			Cavity user
Mockingbird	R	C			X					●			
Gray Catbird	S	C			X					●			
Brown Thrasher	R	C			X					●			Rare in winter
American Robin	R	C		F		N				●			Rare in winter
Eastern Bluebird	R	D		F	F	N				●			Cavity user
Blue-gray Gnatcatcher	S	C			X	X				●			
Cedar Waxwing	W	D				F			●				
Loggerhead Shrike	R	C		F	X					●	●		
White-eyed Vireo	S	C			X					●			
Yellow-throated Vireo	S	D			X					●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

13 SHRUB AND FRUITING TREE SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Black-and white Warbler	S	C		N			F			●			
Blue-winged Warbler	S	C		N		F				●			
Yellow-rumped Warbler	W	C		F	F	F			●	●			
Prairie Warbler	S	C			X					●			
Yellow breasted Chat	S	C		F	X					●			
Orchard Oriole	S	B		F	F	N				●			
Northern Oriole	S	C		F	F	N				●			
Rusty Blackbird	W	D		F					●				
Brewer's Blackbird	W	D		F					●				
Common Grackle	R	B		F		N			●	●			
Brown headed Cowbird	R	B		F	N	N			●	●			Parasitic nester
Cardinal	R	B		F	X				●				
Blue Grosbeak	S	B			X				●				
Indigo Bunting	S	B		F	N				●				
Purple Finch	W	D				F			●				
Pine Siskin	W	C			F	F			●				
American Goldfinch	R	C		X					●	●			
Rufous sided Towhee	R	B			X				●	●			Rare in winter
Tree Sparrow	W	D		F					●				

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

13 SHRUB AND FRUITING TREE SAVANNAH

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Chipping Sparrow	S	D		F	N				●	●			
Field Sparrow	R	B		X	F				●	●			Rare in winter
White-crowned Sparrow	W	D		F					●				
White-throated Sparrow	W	D		F					●				
Fox Sparrow	W	D		F					●				

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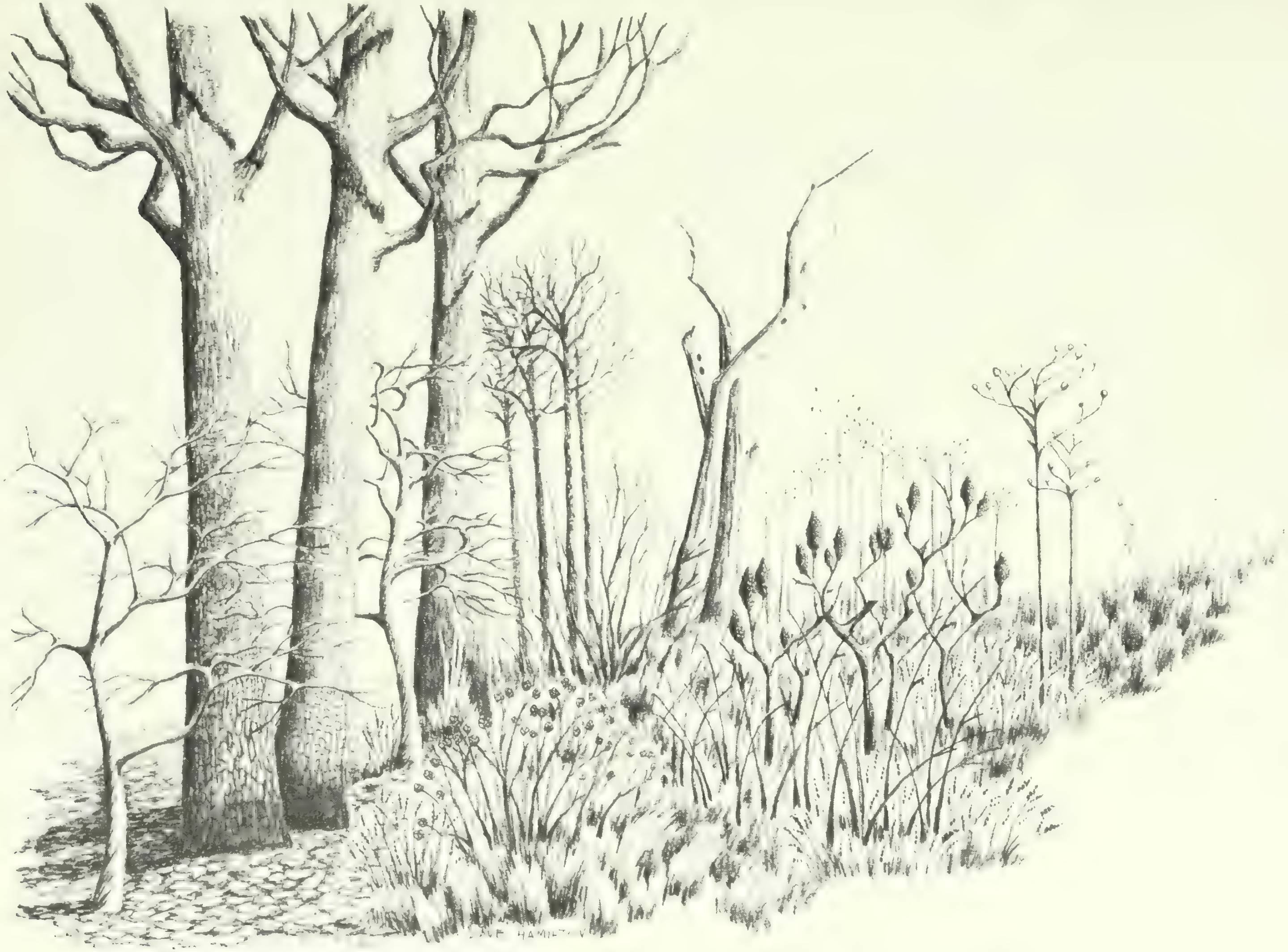
[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)



14 — FOREST AND FIELD EDGE — The forest "edge" can be abrupt or gradual, displaying many kinds and forms of plants.

The kinds of plants vary greatly depending on the site, use of the field, and denseness of the forest border.

14 FOREST AND FIELD EDGE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		X		N					●		Large cavity
Black Vulture	S	E		F							●		
Sharp shinned Hawk	R	E		F		N					●		
Cooper's Hawk	R	D		F		N					●		
Red tailed Hawk	R	C		F		N					●		
Rough legged Hawk	W	D		F							●		
Golden Eagle	W	E		F							●		
American Kestrel	R	C		F		N				●	●		Cavity nester
Bobwhite	R	A		X					●	●			
Mourning Dove	R	C		F		N			●	●			
Yellow billed Cuckoo	S	C			X	F				●			
Black billed Cuckoo	S	E			X	F				●			
Barn Owl	R	D		F		N					●		Cavity nester
Screech Owl	R	C		F		N					●		Cavity nester
Great Horned Owl	R	C		F		N					●		Cavity nester
Barred Owl	R	C		F		N					●		Cavity nester
Chuck will's widow	S	D		N				F		●			
Whip poor will	S	C		N				F		●			
Ruby throated Hummingbird	S	C		F	F	N						●	
Common Flicker	R	C		F		N				●			Cavity excavator

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

14 FOREST AND FIELD EDGE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Red-bellied Woodpecker	R	D				N	F			●			Cavity excavator
Red-headed Woodpecker	R	C				N	F			●			Cavity excavator
Yellow-bellied Sapsucker	W	C					F					●	
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Eastern Kingbird	S	B				N		F		●			
Scissor-tailed Flycatcher	S	D				N		F		●			
Great Crested Flycatcher	S	D				N		F		●			Cavity nester
Eastern Phoebe	S	C						F		●			Nest on beams of old buildings
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	B		F	F	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	C			F	X	F		●	●			Cavity nester
Tufted Titmouse	R	C			F	X			●	●			Cavity nester
White-breasted Nuthatch	R	C				N	F			●			Cavity user
House Wren	S	C		F	X					●			Cavity user
Bewick's Wren	S	D		F	X					●			
Carolina Wren	S	D		F	X					●			Cavity user
Mockingbird	R	B			X					●			
Gray Catbird	S	C			X					●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

14 FOREST AND FIELD EDGE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Brown Thrasher	R	C		F	X					●			Rare in winter
American Robin	R	C		F		N				●			Rare in winter
Eastern Bluebird	R	D		F	F	N				●			Cavity user
Blue-gray Gnatcatcher	S	C			X	X				●			
Golden-crowned Kinglet	W	D				F				●			
Ruby-crowned Kinglet	W	D				F				●			
Loggerhead Shrike	R	C		F	X				●	●			
White-eyed Vireo	S	C			X					●			
Yellow-throated Vireo	S	D			X					●			
Black-and-white Warbler	S	C		N			F			●			
Blue-winged Warbler	S	C		N		F				●			
Northern Parula Warbler	S	D			N	X				●			Prefers low, wet areas
Yellow-rumped Warbler	W	C		F	F	F			●	●			
Chestnut-sided Warbler	S	E			N	F				●			Mostly migrant
Common Yellowthroat	S	C		X	F					●			
Yellow-breasted Chat	S	C		F	X					●			
Orchard Oriole	S	B			N	X				●			
Common Grackle	R	B		F	X	X			●	●			
Brown-headed Cowbird	R	B		F	N	N			●	●			Parasitic nester
Cardinal	R	B		F	X				●				

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[1] Residence: Permanent Resident (R), Summer Resident (S), Winter Resident (W).

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely [illegible] (E).

[3] Forage (F), Nest (N) and Forage and Nest both (X).

14 FOREST AND FIELD EDGE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Rose-breasted Grosbeak	S	D		F	N				●	●			Northern Ozarks only
Blue Grosbeak	S	B			X				●				
Indigo Bunting	S	A		F	N				●	●			
Painted Bunting	S	E		F	X				●	●			Extreme southern Missouri
Evening Grosbeak	W	D				F			●				
Purple Finch	W	D				F			●				
Pine Siskin	W	D			F	F			●				
American Goldfinch	R	C		X					●	●			
Rufous-sided Towhee	R	B			X				●	●			Rare in winter
Dark-eyed Junco	W	A		F					●				
Tree Sparrow	W	C		F					●				
Chipping Sparrow	S	C		F	N				●	●			Grazed field
Field Sparrow	R	A		X	F				●	●			Rare in winter
Harris Sparrow	W	D		F					●				
White-crowned Sparrow	W	C		F					●				
White-throated Sparrow	W	C		F					●				
Fox Sparrow	W	C		F					●				Low areas
Swamp Sparrow	W	D		F					●	●			Low areas
Song Sparrow	R	D		X					●	●			Mostly winter

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[1] Residence: Permanent Resident (R), Summer Resident (S), Winter Resident (W).

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely [illegible] (E).

[3] Forage (F), Nest (N) and Forage and Nest both (X).

15 — GLADES — Glades are natural openings occurring on stony and shallow limestone soils. Plants associated with the glades are the grasses: baldgrass, side oats grama, switchgrass, and little bluestem. Other plants include various prairie forbs (prairie clover, indigo, coneflower, and black-eyed susan) and invading woody species (fragrant sumac, persimmon, and redcedar). Woody plants cover less than 30 percent of the area overhead.

Granite and sandstone glades also occur but they are generally smaller than the limestone glades. The glade communities vary greatly in size, amount and kind of woody cover, direction and steepness of slope, and lushness of herbaceous vegetation.

15 GLADES

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		X		N						●	Cavity or rock ledge for nest
Black Vulture	S	E		F								●	
Red-tailed Hawk	R	B		F		N					●		
Broad winged Hawk	S	D		F							●		
Turkey	R	D		X					●	●			More on granite glades
Killdeer	S	C		X						●			Rare in winter
Mourning Dove	R	C		F		N			●				
Roadrunner	R	E		X	F				●	●	●		
Whip-poor will	S	C		N				F		●			
Common Nighthawk	S	C		N				F		●			
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Eastern Kingbird	S	C				N		F		●			
Horned Lark	R	D		X					●	●			
Blue Jay	R	B			F	X			●	●			
Carolina Chickadee	R	C			F	X	F		●	●			Cavity user
Tufted Titmouse	R	C			F	X			●	●			Cavity user
Black and white Warbler	S	C		N			F			●			
Prairie Warbler	S	B			X	X				●			
Brown headed Cowbird	R	B		F	N					●			Parasitic nester

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

15 GLADES

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Cardinal	R	B		F	X				●				
Blue Grosbeak	S	C			X				●				
Indigo Bunting	S	B		F	N				●	●			
Lark Sparrow	S	C		X						●			
Bachman's Sparrow	S	E		X	F				●	●			
Field Sparrow	S	C		X	F				●	●			Rare in winter

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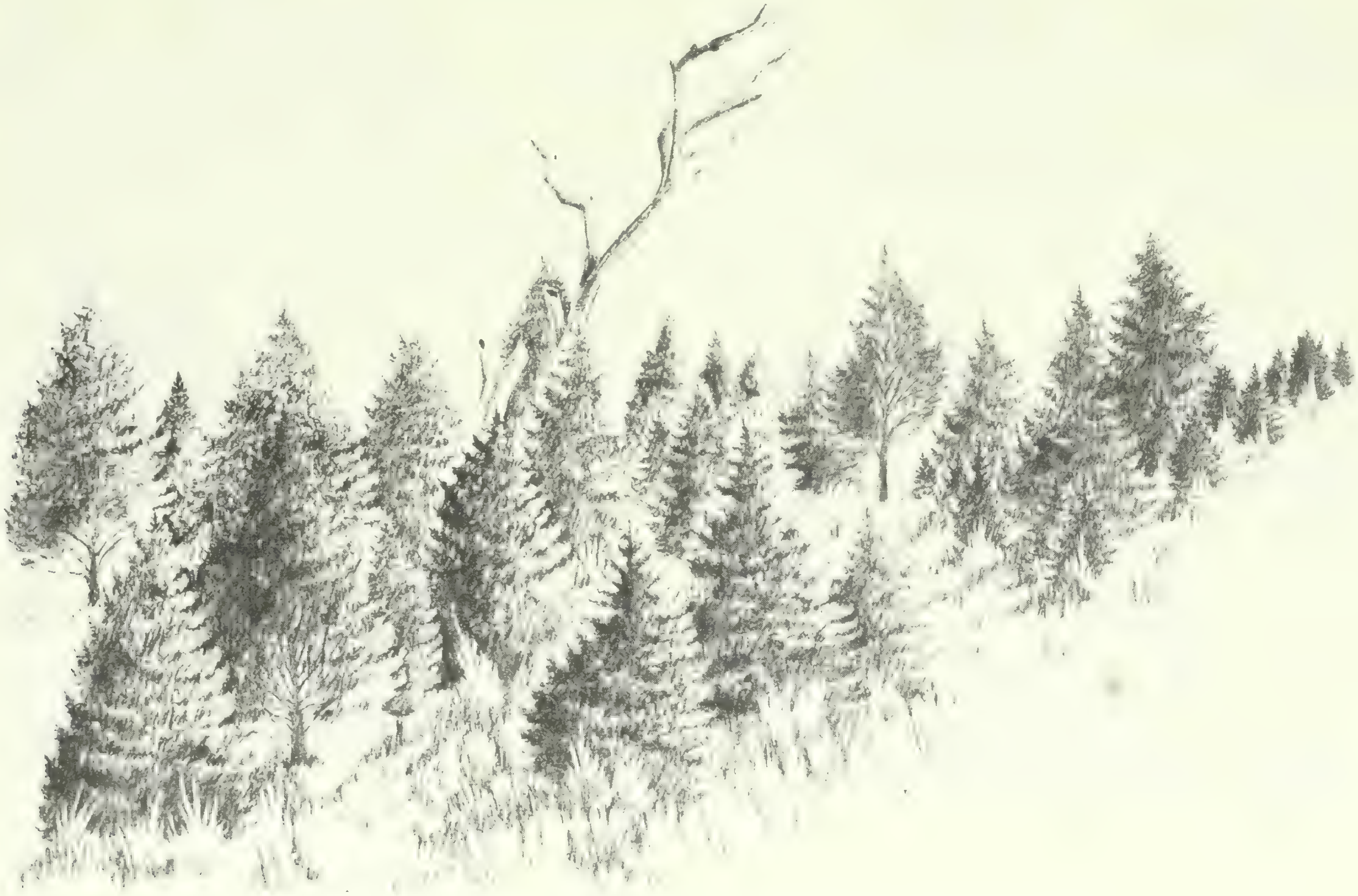
[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)



16 — EASTERN REDCEDAR — The redcedar type occurs in openings on dry, stony, limestone soils or old fields. Areas are more than 30 percent covered by redcedar. The cedars dominate the site; ground cover is sparse under the cedars with a few species of perennial grasses (panic grass, little bluestem) and forbs remaining.

16 EASTERN REDCEDAR

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		F		N						●	Large cavity or rock ledge for nest
Black Vulture	S	E		F								●	
Red-tailed Hawk	R	C		F		N					●		
Broad-winged Hawk	S	D		F							●		
Mourning Dove	R	C		F		N			●				
Yellow-billed Cuckoo	S	C			X	F				●			
Roadrunner	R	E		X					●	●	●		
Screech Owl	R	D		F		N					●		Cavity user
Saw-whet Owl	W	E		F							●		
Chuck-will's-widow	S	E		N				F		●			
Whip-poor-will	S	D		N				F		●			
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Great Crested Flycatcher	S	C				N		F		●			Cavity user
Eastern Wood Pewee	S	D				N		F		●			
Blue Jay	R	B		F	F	X			●	●			
Carolina Chickadee	R	C			F	X	F		●	●			Cavity user
Tufted Titmouse	R	C			F	X			●	●			Cavity user
Mockingbird	R	D			X	X				●			
Gray Catbird	S	D			F	X				●			

[1] Residence Permanent Resident (R) Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

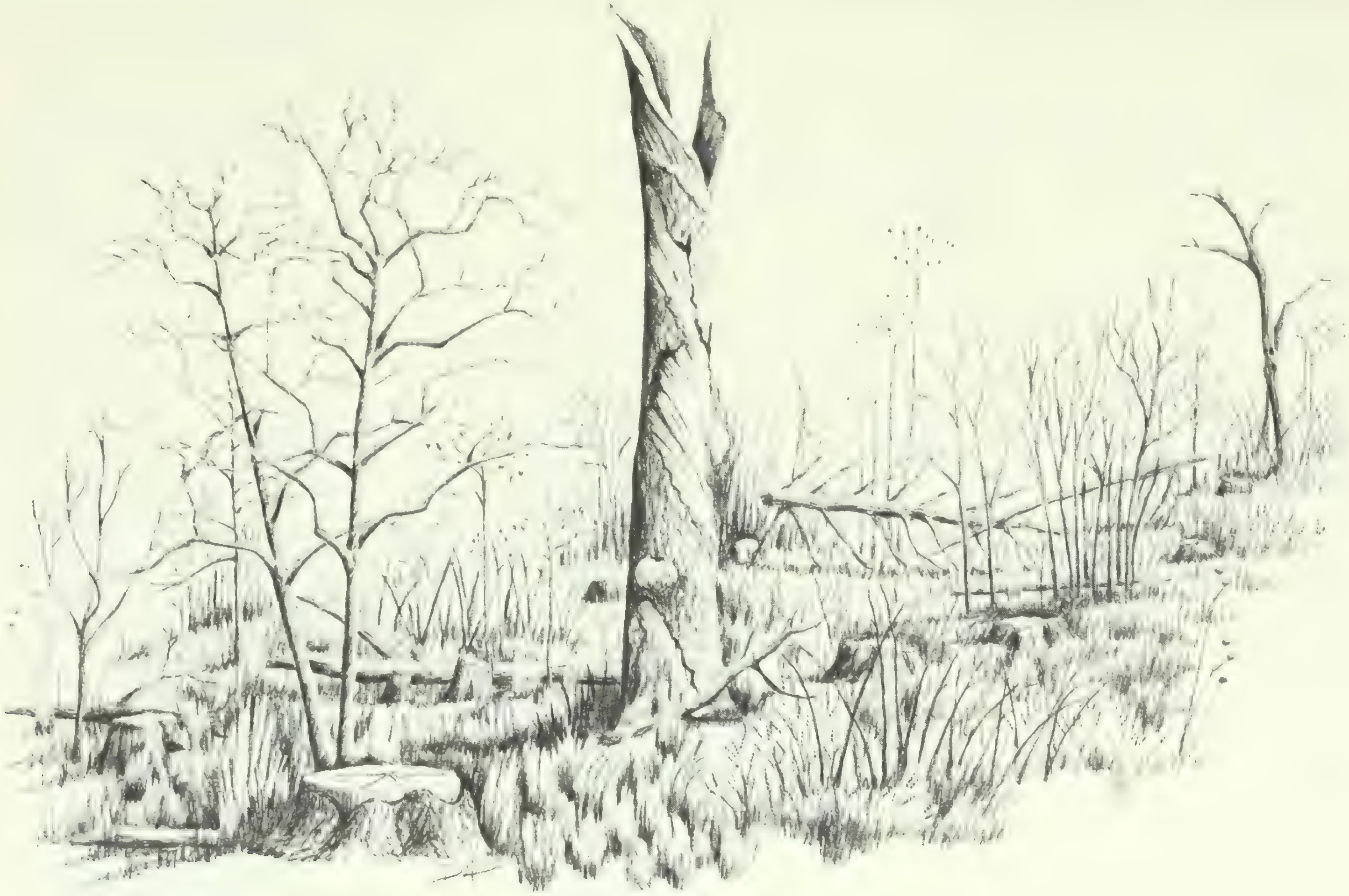
16 EASTERN REDCEDAR

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Brown Thrasher	S	C			X					●			Rare in winter
American Robin	W	B			F				●				Feed on cedar berries
Hermit Thrush	W	D		F					●				
Blue-gray Gnatcatcher	S	C			X	X				●			
Golden-crowned Kinglet	W	D			F	F				●			
Ruby-crowned Kinglet	W	D			F	F				●			
Cedar Waxwing	W	D				F			●				
Black-and-white Warbler	S	C		N			F			●			
Yellow-rumped Warbler	W	D		F	F					●			
Prairie Warbler	S	B			X	X				●			Open stands
Brown-headed Cowbird	R	C		F	N	N				●			Parasitic nester
Cardinal	R	A		F	X	F			●				
Blue Grosbeak	S	C		X					●				
Indigo Bunting	S	C		F	N				●	●			
Painted Bunting	S	F			X	X			●	●			
American Goldfinch	R	C		X					●				
Lark Sparrow	S	D		X					●				Bare ground areas
Field Sparrow	S	D		X	F				●	●			Open stands

[1] Residence Permanent Resident (R) Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)



21 — OAK-HICKORY REGENERATION (HERBACEOUS STAGE) — Forested stands that have been clearcut within the last three years. These stands have many dead and decaying tops and stumps.

Woody plants and herbs vary with site. Woody plants may include various species of oak, hickory, dogwood, sassafras, plum, hazel, blackberry, and sumac. Ground flora usually include sunflowers, aster, pussy toes, thistle, dittany, lespedeza, desmodium, carex, and panic grasses.

There are 3 layers of vegetation; a grass-forb ground flora, scattered shrubs, with a few small trees.

21 OAK-HICKORY REGENERATION (Herbaceous Stage)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		X		N						●	Cavity user
Ruffed Grouse	R	E		X	F				●				
Mourning Dove	R	C		F		N			●				
Ruby-throated Hummingbird	S	C		F	F	N						●	
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Carolina Wren	R	D		F	X					●			Cavity nester
Gray Catbird	S	D			X					●			
Brown Thrasher	R	D			X					●			Rare in winter
White-eyed Vireo	S	B			X					●			
Black-and-white Warbler	S	D		N			F			●			
Yellow-rumped Warbler	W	C		F					●	●			
Chestnut-sided Warbler	S	E			N	F				●			Mostly migrant
Prairie Warbler	S	C			X					●			
Common Yellowthroat	S	C		X	F					●			
Yellow-breasted Chat	S	B		F	X					●			
Brown-headed Cowbird	R	B		F	N				●	●			Parasitic nester
Blue Grosbeak	S	C			X				●				
Indigo Bunting	S	A		F	N				●	●			Near edge
American Goldfinch	R	B		X	F				●	●			

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N) Both Forage and Nest in same level (X)

21 OAK-HICKORY REGENERATION (Herbaceous Stage)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Rufous-sided Towhee	R	A		F	X				●	●			Rare in winter
Lark Sparrow	S	D		X						●			
Bachman's Sparrow	S	E		X	F				●	●			
Dark-eyed Junco	W	C		F					●				
Tree Sparrow	W	C		F					●				
Field Sparrow	S	B		X	F				●	●			Rare in winter
White-throated Sparrow	W	D		F					●				
Fox Sparrow	W	D		F					●				
Swamp Sparrow	W	E		F					●	●			
Song Sparrow	R	D		X					●	●			

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A), Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

22 — OAK-HICKORY REGENERATION (SHRUB-SEEDLING STAGE, STEMS LESS THAN 3 INCHES IN DIAMETER) — Forested stands that were clearcut 5-10 years ago. The many stems of per acre of woody plants nearly cover the area.

The species of oak and hickory that predominate depend on the site. Some sun-loving species such as sassafras, plum, and persimmon remain.

There is essentially one layer of vegetation — trees.

(Shrub-Seedling Stage, Stems Less Than 3 Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Ruffed Grouse	R	E		X	F				●				
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Blue Jay	R	B		F	F	X			●	●			
Gray Catbird	S	D			X					●			
Brown Thrasher	R	C		F	X					●			Rare in winter
Wood Thrush	S	C		F	N					●			
White eyed Vireo	S	C			X					●			
Black-and-white Warbler	S	D		N			F			●			
Worm eating Warbler	S	D		X						●			Steep slopes
Blue winged Warbler	S	C		N		F				●			
Yellow rumped Warbler	W	D				F				●			
Kentucky Warbler	S	C			X					●			
Yellow breasted Chat	S	D		F	X					●			Prefers shorter brush
Brown headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Summer Tanager	S	C			N	X				●			
Cardinal	R	C			X				●				
Indigo Bunting	S	D		F	N				●	●			Near edge
Rufous-sided Towhee	R	B		F	X				●	●			Rare in winter
White throated Sparrow	W	D		F					●				

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

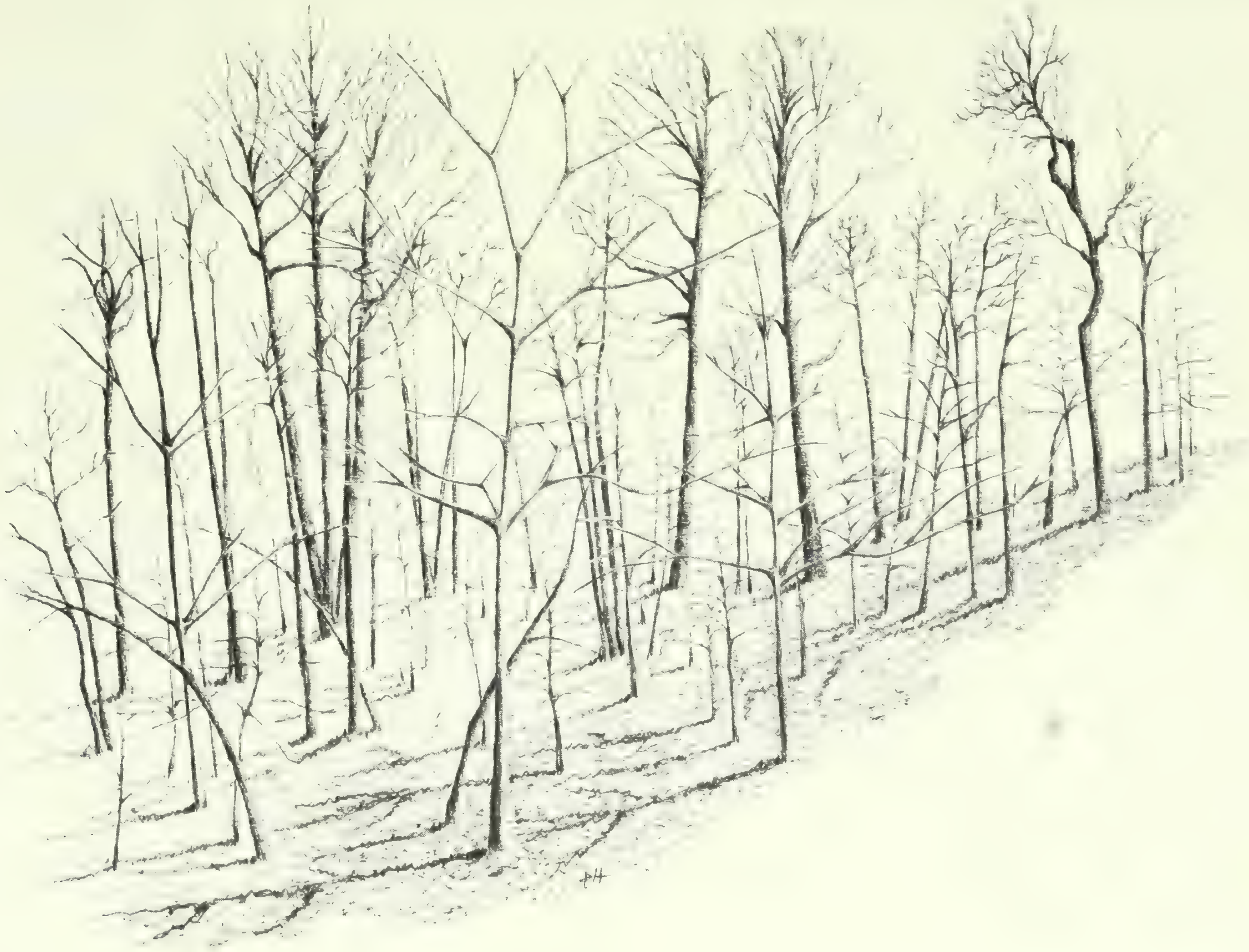
(Shrub-Seedling Stage, Stems Less Than 3 Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Fox Sparrow	W	D		F					●				
Song Sparrow	W	D		F					●				

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)



23 — IMMATURE OAK-HICKORY (POLES AND SAPLINGS, 3-9 INCHES IN DIAMETER) — Dense stands of oak and hickory poles. The kinds of plants and which ones dominate vary with soil, slope, and topographic position.

Shrub and ground flora usually sparse to absent.

These stands are nearly uniform in height.

23 IMMATURE OAK-HICKORY (Poles and Saplings 3-9 Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Ruffed Grouse	R	E		X	F				●				
Yellow billed Cuckoo	S	C			X	F				●			
Whip-poor-will	S	D		N				F		●			
Red-bellied Woodpecker	R	C				N	F			●			Cavity excavator
Red-headed Woodpecker	R	C				N	F			●			Prefers abundant dead wood
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Blue Jay	R	B		F	F	X			●	●			
Carolina Chickadee	R	C			F	X	F		●	●			Cavity user
Tufted Titmouse	R	C			F	X			●	●			Cavity user
White-breasted Nuthatch	R	D				N	F			●			Cavity user
Brown Creeper	W	D					F			●			
Hermit Thrush	W	D		F					●				
Blue gray Gnatcatcher	S	C			N	F				●			
Red-eyed Vireo	S	C				X				●			
Warbling Vireo	S	D				X				●			More common near streams
Black-and-white Warbler	S	C		N			F			●			
Blue-winged Warbler	S	D		N		F				●			Prefers edge
Yellow-rumped Warbler	W	D			F	F			●	●			
Cerulean Warbler	S	C			N	F				●			

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A), Moderately Abundant (B) Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

23 IMMATURE OAK-HICKORY (Poles and Saplings 3-9 Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Ovenbird	S	C		X						●			
Hooded Warbler	S	E			X					●			
American Redstart	S	D			N	X		F		●			Prefers bottomland forests
Brown-headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Summer Tanager	S	C			N	X				●			
Cardinal	R	C			X				●				

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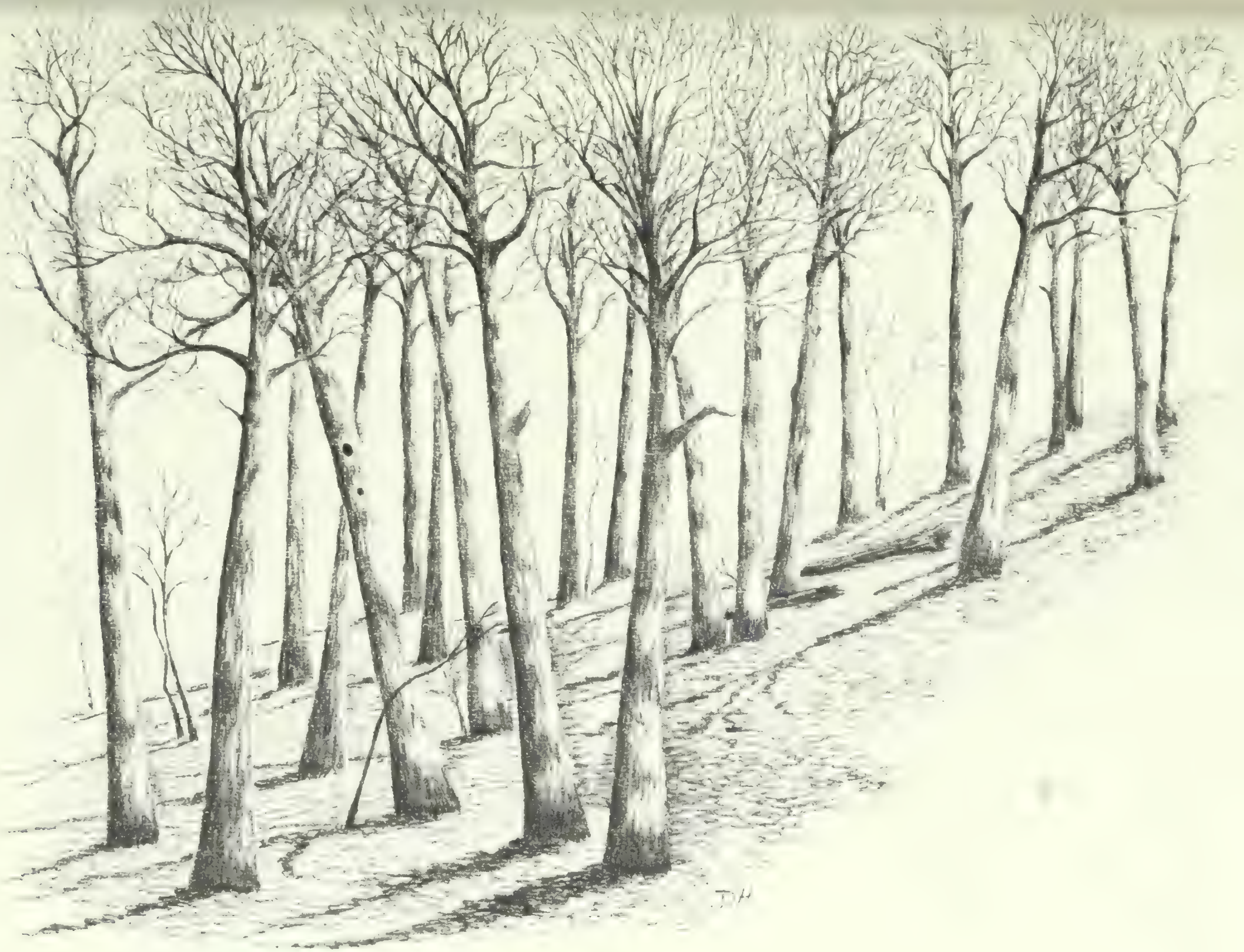
[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N) Both Forage and Nest in same level (X)



24 — MATURE OAK-HICKORY (OPEN UNDERGROWTH) — Overstory trees usually include mixtures of black, white, and post oaks with hickories. Occasionally pure stands of black, white, or post oak are found. These are dense stands with closed canopies growing on dry sites such as ridges and south and west slopes.

Mid-story plants are sparse to non-existent.

Ground plants are normally sparse and include goat's-rue, dittany, cinquefoil, American fever few, woody betony, lespedeza, little bluestem, panic grass, and sorrel.

24 MATURE OAK-HICKORY (Open Undergrowth)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Sharp-skinned Hawk	R	E		F		N		F			●		Prefers conifers
Cooper's Hawk	R	D		F		N		F			●		Prefers conifers
Broad-winged Hawk	S	D		F		N					●		
Ruffed Grouse	R	E		X	F				●				
Turkey	R	C		X					●	●			
Yellow billed Cuckoo	S	C			F	X				●			
Black-billed Cuckoo	S	D			F	X				●			
Schreech Owl	R	D		F		N					●		Cavity nester
Great Horned Owl	R	D		F		N					●		Prefers cavities for nesting
Barred Owl	R	E		F		N					●		Cavity nester
Chuck will's widow	S	E		N				F		●			
Whip poor will	S	C		N				F		●			
Pileated Woodpecker	R	D				N	F			●			Cavity excavator
Red bellied Woodpecker	R	C				N	F			●			Cavity excavator
Red-headed Woodpecker	R	D				N	F			●			Cavity excavator
Great Crested Flycatcher	S	C				N		F		●			Cavity nester
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	C		F	F	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	C				X				●			Cavity nester

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

24 MATURE OAK-HICKORY (Open Undergrowth)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Tufted Titmouse	R	A				X				●			Cavity nester
White-breasted Nuthatch	R	C				N	F			●			Cavity nester
Brown Creeper	W	D					F			●			
Wood Thrush	S	C		F	N					●			
Blue-gray Gnatcatcher	S	C			N	F				●			
Yellow-throated Vireo	S	E			X					●			
Red eyed Vireo	S	B				X				●			
Warbling Vireo	S	D				X				●			More common near streams
Black and white Warbler	S	C		N			F			●			
Worm-eating Warbler	S	C		X						●			Steep slopes
Ovenbird	S	C		X						●			
Kentucky Warbler	S	D			X					●			
Hooded Warbler	S	D			X					●			
American Redstart	S	D			N	X		F		●			More common near streams
Brown headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Scarlet Tanager	S	C		F		N				●			
Summer Tanager	S	B			N	X		F		●			
Cardinal	R	C			X				●				
Pine Siskin	W	D				F			●				

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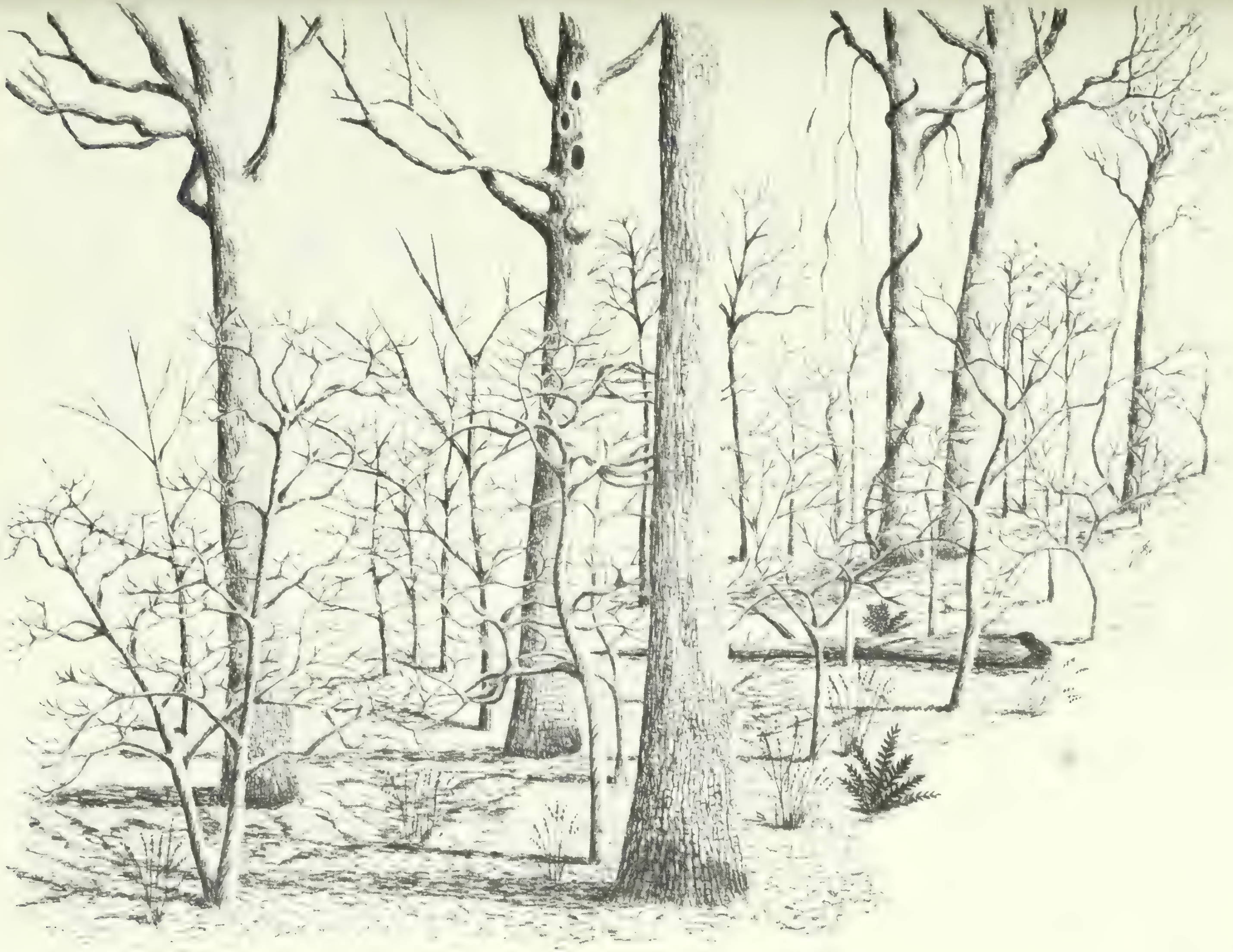
[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)



25 — MATURE OAK-HICKORY (DENSE UNDERGROWTH) — Overstory trees vary from mixtures of black, northern, and white oak, and hickory to nearly pure stands of white oak, northern red oak, and black oak.

Mid-story plants are representative of shade tolerant species such as flowering dogwood, ironwood, white oak, black gum, and sugar maple.

Ground plants usually include Virginia creeper, various species of beggar tick, gallium, avens, and false solomon's seal.

25 MATURE OAK-HICKORY (Dense Undergrowth)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Sharp-shinned Hawk	R	E		F		N		F			●		
Broad-winged Hawk	S	D		F		N					●		
Ruffed Grouse	R	E		X	F				●				
Turkey	R	C		X					●	●			
Yellow-billed Cuckoo	S	C			X	F				●			
Black-billed Cuckoo	S	D			X	F				●			
Pileated Woodpecker	R	E				X	F			●			Cavity excavator
Red-bellied Woodpecker	R	C				N	F			●			Cavity excavator
Hairy Woodpecker	R	C				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Great Crested Flycatcher	S	B				N		F		●			Cavity nester
Acadian Flycatcher	S	D				N		F		●			Prefers streamside trees
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	C			F	X			●	●			
Carolina Chickadee	R	D			F	X	F			●			Cavity nester
Tufted Titmouse	R	B			F	X			●	●			Cavity nester
White-breasted Nuthatch	R	C				N	F			●			Cavity nester
Brown Creeper	W	D					F			●			
Winter Wren	W	D			F					●			
Carolina Wren	R	C			F	X				●			Cavity nester

[1] Residence Permanent Resident (R), Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N) Both Forage and Nest in same level (X)

25 MATURE OAK-HICKORY (Dense Undergrowth)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Wood Thrush	S	C		F	N					●			
Hermit Thrush	W	D		F					●	●			
Blue-gray Gnatcatcher	S	C			X	F				●			
Yellow-throated Vireo	S	E			X					●			
Red-eyed Vireo	S	A				X				●			
Warbling Vireo	S	D				X				●			More common near streams
Black-and-white Warbler	S	C		N			F			●			
Worm-eating Warbler	S	C		X						●			Steep slopes
Northern Parula Warbler	S	D			N	X				●			Prefers bottomland forests
Ovenbird	S	B		X						●			
Kentucky Warbler	S	B			X					●			
Hooded Warbler	S	D			X					●			
American Redstart	S	D			N	X		F		●			More common near streams
Brown-headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Scarlet Tanager	S	C		F		N				●			
Summer Tanager	S	B			N	X		F		●			
Cardinal	R	C			X				●				
Pine Siskin	W	D				F			●				

[1] Residence Permanent Resident (R) Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

26 — OLD-GROWTH OAK-HICKORY — Stands that are usually more than 100 years old. The kinds of trees and plants found here vary, depending on soil, slope, and topographic position.

Depending on the site, these stands usually vary a lot in height, contain some trees with cavities, and have occasional snags. Ground plants are fairly numerous.

26 OLD-GROWTH OAK-HICKORY

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		X		N						●	Cavity nester
Goshawk	W	E		F				F			●		
Sharp-shinned Hawk	R	E		F		N					●		
Cooper's Hawk	R	E		F		N					●		
Red-tailed Hawk	R	C		F		N					●		
Red-shouldered Hawk	R	E		F		N					●		
Broad-winged Hawk	S	D		F		N					●		
American Kestrel	R	D		F		N		F			●		Cavity nester
Turkey	R	C		X					●	●			
Yellow billed Cuckoo	S	C			F	X				●			
Black-billed Cuckoo	S	D			F	X				●			
Barn Owl	R	E		F		N					●		Cavity nester
Screech Owl	R	D		F		N					●		Cavity nester
Great Horned Owl	R	D		F		N					●		Cavity nester
Barred Owl	R	D		F		N					●		Cavity nester
Saw whet Owl	W	E		F							●		
Chuck will's widow	S	D		N				F		●			
Whip poor will	S	C		N				F		●			
Chimney Swift	S	D				N		F		●			Cavity nester
Common Flicker	R	C		F		N				●			Cavity excavator

[1] Residence Permanent Resident (R) Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

26 OLD-GROWTH OAK-HICKORY

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Pileated Woodpecker	R	D				N	F			●			Cavity excavator
Red-bellied Woodpecker	R	C				N	F			●			Cavity excavator
Red-headed Woodpecker	R	C				N	F		●	●			Cavity excavator
Yellow-bellied Sapsucker	W	D					F					●	Cavity excavator
Hairy Woodpecker	R	C				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Great Crested Flycatcher	S	C				X		F		●			Cavity nester
Eastern Phoebe	S	C						F		●			Nests on buildings, bridges, cliffs
Acadian Flycatcher	S	D				N		F		●			Prefers streamside trees
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	B		F	F	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	C			F	X	F			●			Cavity nester
Tufted Titmouse	R	B			F	X				●			Cavity nester
White breasted Nuthatch	R	C				N	F			●			Cavity nester
Brown Creeper	W	D					F			●			
House Wren	S	D			F	N				●			Cavity nester
Winter Wren	W	D			F					●			
Carolina Wren	R	D			X					●			Cavity nester
Brown Thrasher	R	D		F	X				●	●			Rare in winter

[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

26 OLD-GROWTH OAK-HICKORY

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Wood Thrush	S	C		F	N					●			
Hermit Thrush	W	D		F	F				●	●			
Eastern Bluebird	R	D		F		N		F		●			Cavity nester
Blue-gray Gnatcatcher	S	C			F	X				●			
Cedar Waxwing	W	D			F				●				
Yellow throated Vireo	S	D			F	X				●			
Red-eyed Vireo	S	A				X				●			
Warbling Vireo	S	D				X				●			
Black and-white Warbler	S	C		N			F			●			
Worm-eating Warbler	S	C		X						●			Steep slope
Northern Parula Warbler	S	C			N	X				●			Prefers low, wet areas
Yellow rumped Warbler	W	D		F	F					●			
Cerulean Warbler	S	C			N	X				●			
Yellow throated Warbler	S	D			N	X				●			
Ovenbird	S	B		X						●			
Kentucky Warbler	S	B			X					●			
Hooded Warbler	S	D			X					●			
Orchard Oriole	S	D			N	X				●			
Northern Oriole	S	B				X				●			
Common Grackle	R	D		F		X			●	●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

26 OLD-GROWTH OAK-HICKORY

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Brown-headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Scarlet Tanager	S	C		F		N				●			
Summer Tanager	S	C			N	X		F		●			
Cardinal	R	D			X				●				
Purple Finch	W	D				F			●				
Pine Siskin	W	D				F			●				
Chipping Sparrow	S	D		F	N				●				

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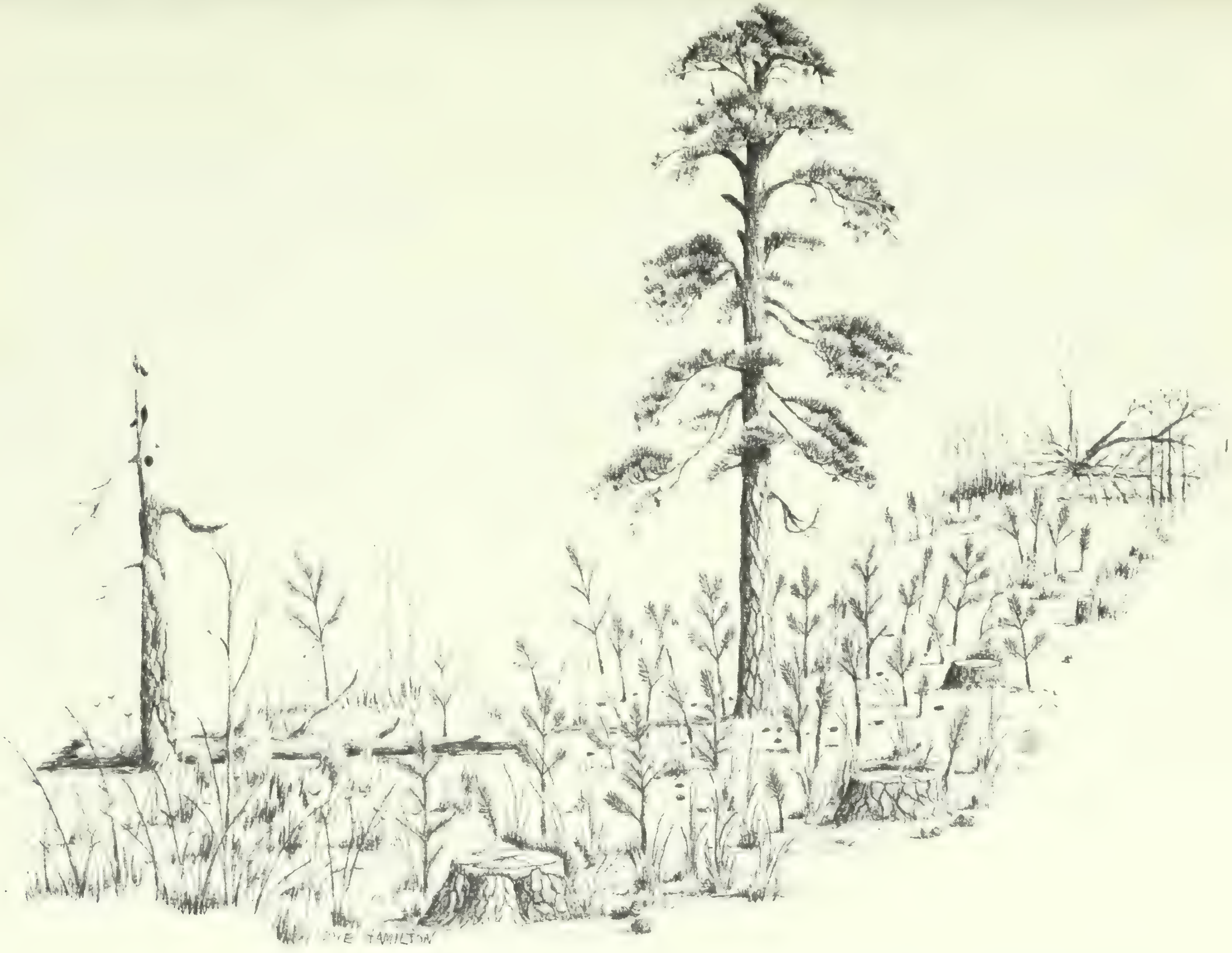
[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)



31 — SHORTLEAF PINE REPRODUCTION (0-3 INCHES IN DIAMETER) — The seed trees that are often left standing make these stands more diverse.

The density of shortleaf pine seedlings varies appreciably. Deciduous species occurring with the pine are sassafras, hickory, various species of oak, dogwood, plum, hawthorne, and black gum.

The ground plants may include blackberry, sumac, gooseberry, poison ivy, pussy toes, dittany, sunflower, poverty oat grass, panic grass, carex, and little bluestem.

31 SHORTLEAF PINE REPRODUCTION (0-3 Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	S	C		X		N						●	Cavity nester
Bobwhite	R	C		X					●	●			
Mourning Dove	R	C		F	N	N			●				
Common Nighthawk	S	D		N				F		●			
Ruby-throated Hummingbird	S	D		F	N							●	
Common Flicker	R	C		F						●			Nest if snags are present
Yellow bellied Sapsucker	W	C					F					●	
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	D				N	F			●			Cavity excavator
Common Crow	R	C		F		N			●				Primarily a feeding area
Gray Catbird	S	C		F	X					●			
Brown Thrasher	R	C		F	X					●			Rare in winter
White eyed Vireo	S	C			X					●			
Prairie Warbler	S	C			X					●			
Common Yellowthroat	S	C		N	F					●			
Yellow-breasted Chat	S	B		F	X					●			
Brown headed Cowbird	R	C		F	N				●	●			Parasitic nester
Blue Grosbeak	S	D			X				●				
American Goldfinch	R	C		X	F				●	●			Rare in winter
Rufous sided Towhee	R	B		F	N				●	●			Rare in winter

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C), Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

31 SHORTLEAF PINE REPRODUCTION (0-3 Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Lark Sparrow	S	D		X						●			
Bachman's Sparrow	S	E		X						●			
Dark-eyed Junco	W	C		F					●				
Tree Sparrow	W	D		F					●				
Field Sparrow	R	C		X	N					●			Rare in winter
White-throated Sparrow	W	D		F					●				
Fox Sparrow	W	D		F					●				
Swamp Sparrow	W	D		F					●				
Song Sparrow	W	D		F					●				

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N), Both Forage and Nest in same level (X)

32 — IMMATURE SHORTLEAF PINE (3-9 INCHES IN DIAMETER) — Shortleaf pine stands of this size are usually dense with tree tops touching.

Small trees and shrubs are sparse to non-existent.

Ground plants are equally limited because of the shade and thick bed of needles.

32 IMMATURE SHORTLEAF PINE (3-9 Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Saw-whet Owl	W	E		F							●		
Chuck-will's widow	S	E		N				F		●			
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Blue Jay	R	C			F	X			●	●			
Tufted Titmouse	R	C				X				●			Cavity nester
White breasted Nuthatch	R	D				N	F			●			Cavity nester
Red-breasted Nuthatch	W	D					F			●			Cavity user
Brown-headed Nuthatch	R	E				N	F			●			Cavity nester
Brown Creeper	W	D					F			●			
Winter Wren	W	D			F					●			
Golden crowned Kinglet	W	D				F				●			
Ruby-crowned Kinglet	W	D				F				●			
Blue winged Warbler	S	C		N	F	F				●			
Yellow breasted Chat	S	C		F	X					●			
Brown-headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Cardinal	R	C		F	X				●	●			
Evening Grosbeak	W	D				F			●				
Pine Siskin	W	D				F			●				

[1] Residence Permanent Resident (R) Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in [illegible] (X)

33 — MATURE SHORTLEAF PINE (9 + INCHES IN DIAMETER) — Sawlog-size shortleaf pine has usually been thinned two or three times. The amount and kind of undergrowth depends on the basal area[2] and site characteristics such as soil depth and steepness of slope. Tree heights are very uniform

[2] *Basal area is the total cross-sectional area of all the trees growing on a given area of land. This is a standard measure of density of forests.*

33 MATURE SHORTLEAF PINE (9+ Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Sharp-shinned Hawk	R	D				N		F			●		
Cooper's Hawk	R	D				N		F			●		
Broad-winged Hawk	S	D		F		N					●		
Turkey	R	C		X					●	●			
Yellow-billed Cuckoo	S	C			X	X				●			
Screech Owl	R	D		F		N					●		Cavity nester
Great Horned Owl	R	C		F		N					●		
Barred Owl	R	D		F		N					●		Cavity nester
Long eared Owl	W	D		F							●		
Saw-whet Owl	W	D		F							●		
Chuck-will's-widow	S	D		N				F		●			
Whip-poor-will	S	C		N				F		●			
Pileated Woodpecker	R	E				N	F			●			Cavity excavator
Red bellied Woodpecker	R	D				N	F			●			Cavity excavator
Yellow-bellied Sapsucker	W	D					F					●	
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	C		F		X			●	●			
Common Crow	R	C		F		N			●	●			

[1] Residence Permanent Resident (R) Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

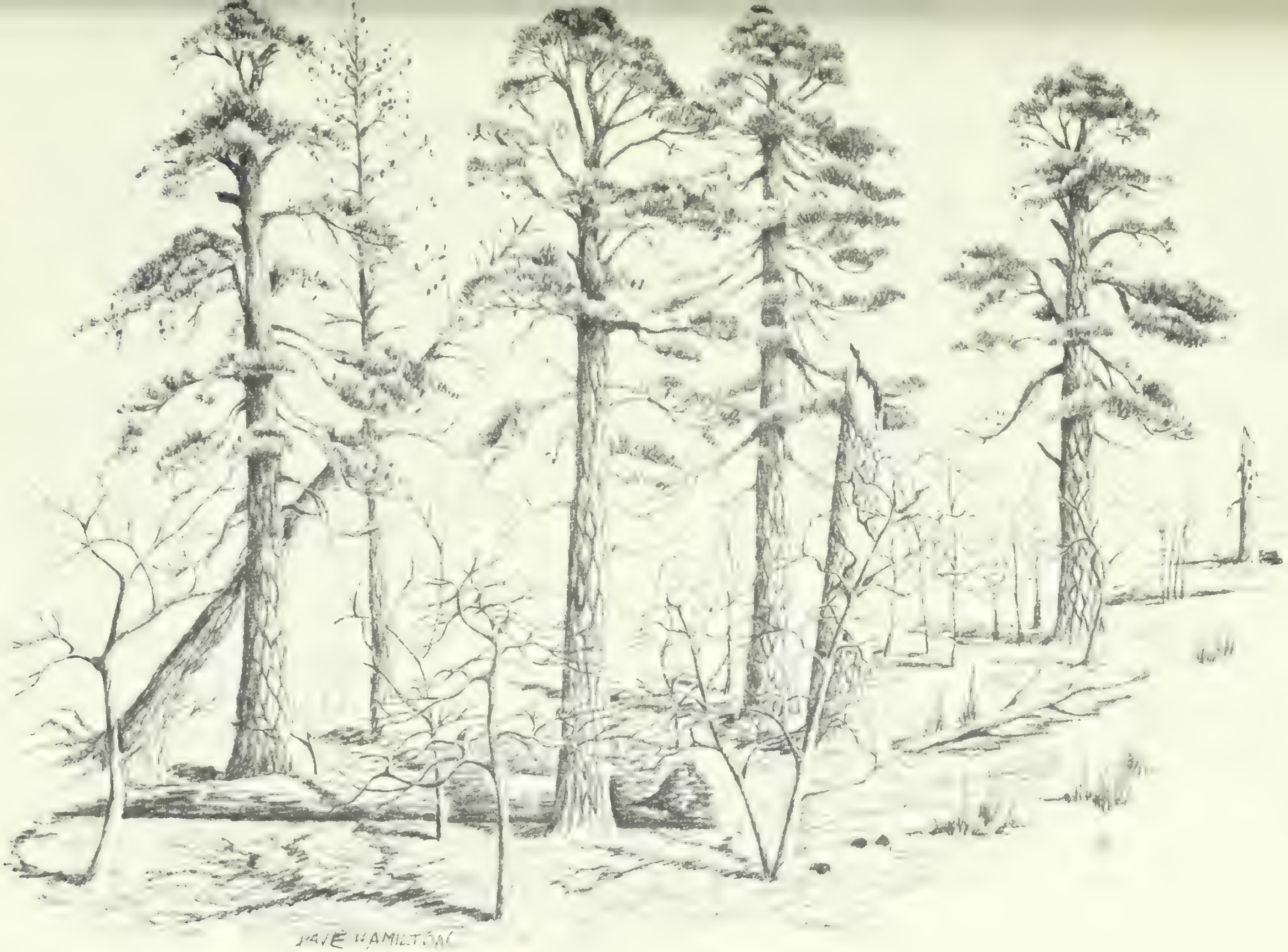
33 MATURE SHORTLEAF PINE (9+ Inches in Diameter)

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Carolina Chickadee	R	D				X				●			Cavity user
Tufted Titmouse	R	B				X				●			Cavity user
White-breasted Nuthatch	R	C				N	F			●			Cavity user
Red-breasted Nuthatch	W	C					F			●			
Brown-headed Nuthatch	R	E				N	F			●			Cavity user
Brown Creeper	W	D					F			●			
Winter Wren	W	D			F					●			
Carolina Wren	R	D			X	N				●			Cavity user
Golden-crowned Kinglet	W	D				F				●			
Ruby-crowned Kinglet	W	D				F				●			
Yellow-throated Vireo	S	E				X				●			
Red-eyed Vireo	S	B				X				●			
Black-and-white Warbler	S	C		N		F				●			
Northern Parula Warbler	S	C			N	X				●			Prefers low, wet areas
Yellow-throated Warbler	S	D				X				●			
Pine Warbler	S	C			N	X				●			Rare in winter
Brown-headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Cardinal	R	C		F	X				●				
Pine Siskin	W	D			F	F			●				

[1] Residence Permanent Resident (R) Summer Resident (S) and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)



34 — OLD-GROWTH SHORTLEAF PINE — Stands of nearly pure pine that are 90 years of age or older.

The crowns of these old, large trees are usually farther apart than in younger stands allowing a well developed understory. Hickory, various species of oak, dogwood, and sassafras are often found in the mid-story. Common shrubs include sumac and huckleberry.

Ground plants include such plants as pussy toes, American fever few, lespedeza, sedges, and little bluestem.

There is usually a wide range of tree heights and an appearance of "layering" in old growth pine stands.

34 OLD-GROWTH SHORTLEAF PINE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	R	D		F		N						●	Cavity nester
Black Vulture	R	D		F		N						●	Cavity nester
Goshawk	W	E		F				F			●		
Sharp-shinned Hawk	R	D		F		N		F			●		
Cooper's Hawk	R	D		F		N		F			●		
Red-shouldered Hawk	R	D		F		N					●		Prefers streamside trees for nests
Broad winged Hawk	S	D		F	N						●		
American Kestrel	R	D		F		N				●	●		Cavity nester
Turkey	R	C		X					●	●			
Yellow billed Cuckoo	S	C			X	X				●			
Screech Owl	R	E		F		N					●		Cavity nester
Great Horned Owl	R	D		F		N					●		
Barred Owl	R	E		F		N					●		Cavity nester
Long eared Owl	W	E		F							●		
Saw whet Owl	W	E		F							●		
Whip-poor will	S	D		N				F		●			
Chimney Swift	S	D				N		F		●			Cavity nester
Common Flicker	R	C		F		N				●			Cavity excavator
Pileated Woodpecker	R	D				N	F			●			Cavity excavator
Red bellied Woodpecker	R	C				N	F			●			Cavity excavator

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest at same level (X)

34 OLD-GROWTH SHORTLEAF PINE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Red-headed Woodpecker	R	C				N	F		●	●			Cavity excavator
Yellow-bellied Sapsucker	W	D					F					●	
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Red-cockaded Woodpecker	R	E				N	F			●			Cavity excavator
Great Crested Flycatcher	S	C				N		F		●			Cavity nester
Eastern Wood Pewee	S	C				N		F		●			
Blue Jay	R	C		F	F	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	D				X	F			●			Cavity nester
Tufted Titmouse	R	B			F	X				●			Cavity nester
White breasted Nuthatch	R	C				N	F			●			Cavity nester
Red-breasted Nuthatch	W	D					F			●			Cavity user
Brown headed Nuthatch	R	E				N	F			●			Cavity nester
Brown Creeper	W	D					F			●			
Winter Wren	W	D			F					●			
Carolina Wren	R	D			X	N				●			Cavity nester
Brown Thrasher	R	D		F	X					●			Rare in winter
Golden crowned Kinglet	W	D				F				●			
Ruby crowned Kinglet	W	D				F				●			

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest at same level (X)

34 OLD-GROWTH SHORTLEAF PINE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Yellow-throated Vireo	S	E				X				●			
Red-eyed Vireo	S	D				X				●			
Black-and-white Warbler	S	C		N		F				●			
Northern Parula Warbler	S	C			N	X				●			
Yellow-rumped Warbler	W	C		F	F				●	●			
Pine Warbler	S	C			N	X				●			Rare in winter
Brown-headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Cardinal	R	D		X	X				●				
Purple Finch	W	D				F			●				
Pine Siskin	W	D				F			●				

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A), Moderately Abundant (B) Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest at same level (X)

41 — WOODED STREAMSIDE AND BOTTOMLAND HARDWOODS — A woodland habitat within the floodplain of a stream. The plants found depend on the development and maturity of the stream. Small and youthful streams have willow, witch-hazal, alder, sycamore, sandgrape, and ninebark nearby. Farther away from the margin of the stream on the alluvial deposits are cottonwood, silver maple, and green ash. Older and more mature streams are bordered by elm, green ash, sycamore, and sugar maple. Other trees and shrubs found in the last stage are black walnut, sourgum, butternut, honeylocust, bur oak, hophornbeam, elderberry, blackhaw, moonseed, and buckeye. This is a highly productive and diverse habitat.

41 WOODED STREAMSIDE AND BOTTOMLAND HARDWOODS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Great Blue Heron	S	D	F			N					●		
Green Heron	S	C	F			N					●		
Great Egret	S	E	F								●		
Mallard.	R	C	F	X					●	●			Rare in summer
Wood Duck	R	C	F			N			●	●			Cavity nester
Common Goldeneye	W	D	F							●			
Hooded Merganser	S	D	F			N				●	●		Cavity nester
Turkey Vulture	R	C		X		N						●	Cavity nester
Black Vulture	S	E		X		N						●	
Sharp-shinned Hawk	R	E		F		N		F			●		
Cooper's Hawk	R	E		F		N		F			●		
Red tailed Hawk	R	C		F		N					●		
Red-shouldered Hawk	R	D		F		N					●		Preferred habitat
Broad winged Hawk	S	D		F		N					●		
Golden Eagle	W	E		F							●		
Bald Eagle	W	E	F	F							●		
Osprey	S	E	F			N					●		Potential nester
American Kestrel	R	D		F		N		F			●		Cavity nester
Ruffed Grouse	R	E		X					●	●			
American Woodcock	S	C		X						●			

[1] Residence Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N), Both Forage and Nest in same level (X)

41 WOODED STREAMSIDE AND BOTTOMLAND HARDWOODS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Spotted Sandpiper	S	C	F	N						●			
Herring Gull	W	D	F							●			
Ring-billed Gull	W	D	F							●			
Mourning Dove	R	C		F	N	N			●				
Yellow billed Cuckoo	S	C			X	X				●			
Black-billed Cuckoo	S	D			X	X				●			
Screech Owl	R	D		F		N					●		Cavity nester
Great Horned Owl	R	D		F		N					●		
Barred Owl	R	D		F		N					●		Cavity nester
Chuck-will's-widow	S	D		N				F			●		
Whip poor-will	S	C		N				F			●		
Ruby-throated Hummingbird	S	C		F	F	N						●	
Belted Kingfisher	R	B	F	N							●		Mud bank nester
Common Flicker	R	C		F		N				●			Cavity excavator
Pileated Woodpecker	R	D				N	F			●			Cavity excavator
Red bellied Woodpecker	R	C				N	F			●			Cavity excavator
Red-headed Woodpecker	R	C				N	F			●			Cavity excavator
Yellow-bellied Sapsucker	W	C					F					●	Cavity user
Hairy Woodpecker	R	C				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator

[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

41 WOODED STREAMSIDE AND BOTTOMLAND HARDWOODS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Eastern Kingbird	S	C				N		F		●			
Great Crested Flycatcher	S	C				N		F		●			Cavity nester
Eastern Phoebe	S	C						F		●			Nests in buildings, bridges, caves
Acadian Flycatcher	S	C				N		F		●			Preferred habitat
Eastern Wood Pewee	S	C				N		F		●			
Tree Swallow	S	E				N		F		●			Cavity nester
Bank Swallow	S	C						F		●			Mud bank nester
Rough-winged Swallow	S	C						F		●			Rock face nester
Blue Jay	R	C		F	F	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	D			F	X	F			●			Cavity nester
Tufted Titmouse	R	C			F	X				●			Cavity nester
White-breasted Nuthatch	R	C				N	F			●			Cavity nester
Brown Creeper	W	D					F			●			
Winter Wren	W	D			F					●			
Bewick's Wren	S	D			F	X				●			Cavity nester
Carolina Wren	R	C			X	N				●			Cavity nester
Mockingbird	R	C		X	X				●	●			
Gray Catbird	S	C			X					●			
Brown Thrasher	R	C		F	X				●	●			Rare in winter

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

41 WOODED STREAMSIDE AND BOTTOMLAND HARDWOODS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
American Robin	R	C		F	N	N			●	●			
Wood Thrush	S	C		F	N					●			
Hermit Thrush	W	D		F					●	●			
Blue-gray Gnatcatcher	S	C			N	F				●			
Golden-crowned Kinglet	W	D				F				●			
Ruby-crowned Kinglet	W	D				F				●			
Cedar Waxwing	R	D			F	X			●				
Yellow-throated Vireo	S	D				X				●			
Red eyed Vireo	S	A				X				●			
Warbling Vireo	S	C				X				●			Preferred habitat
Black-and-white Warbler	S	C		N	F	F				●			
Prothonotary Warbler	S	C				X				●			Cavity nester
Swainson's Warbler	S	E		F	N					●			Large canebreaks
Worm-eating Warbler	S	C			X					●			
Bachman's Warbler	S	E			N	F				●			May be extinct
Northern Parula Warbler	S	C			N	X				●			Preferred habitat
Yellow Warbler	S	C			N	F				●			
Yellow-rumped Warbler	W	C		F	F	F				●			
Cerulean Warbler	S	C			N	F				●			
Yellow-throated Warbler	S	D			N	X				●			

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

41 WOODED STREAMSIDE AND BOTTOMLAND HARDWOODS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Ovenbird	S	B		X						●			
Louisiana Waterthrush	S	C		X						●			
Kentucky Warbler	S	B			X					●			
Common Yellowthroat	S	C		N	F					●			
Hooded Warbler	S	D			X					●			
American Redstart	S	D			N	X		F		●			Preferred habitat
Red-winged Blackbird	R	B		X					●	●			
Orchard Oriole	S	C			N	X				●			
Northern Oriole	S	C			X	X				●			
Rusty Blackbird	W	D		F					●				
Brewer's Blackbird	W	D		F					●				
Brown-headed Cowbird	R	C		F	N	N			●	●			Parasitic nester
Scarlet Tanager	S	C		F		N				●			
Summer Tanager	S	C			N	X		F		●			
Cardinal	R	C			X				●				
Indigo Bunting	S	B		F	N				●	●			
American Goldfinch	R	D		X					●	●			More common in winter
Rufous-sided Towhee	R	B		F	X				●	●			Rare in winter
Harris Sparrow	W	D		F					●				
Swamp Sparrow	W	D		F					●				

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

41 WOODED STREAMSIDE AND BOTTOMLAND HARDWOODS

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Song Sparrow	W	D		F					●				

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[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

42 — WATERHOLE — Manmade ponds usually 1/10-acre or less and located in a wooded environment. They are primarily fishless, although some have been stocked with various species of fish. The dam and about an acre adjacent to the pond are maintained in an open to semi-open condition.

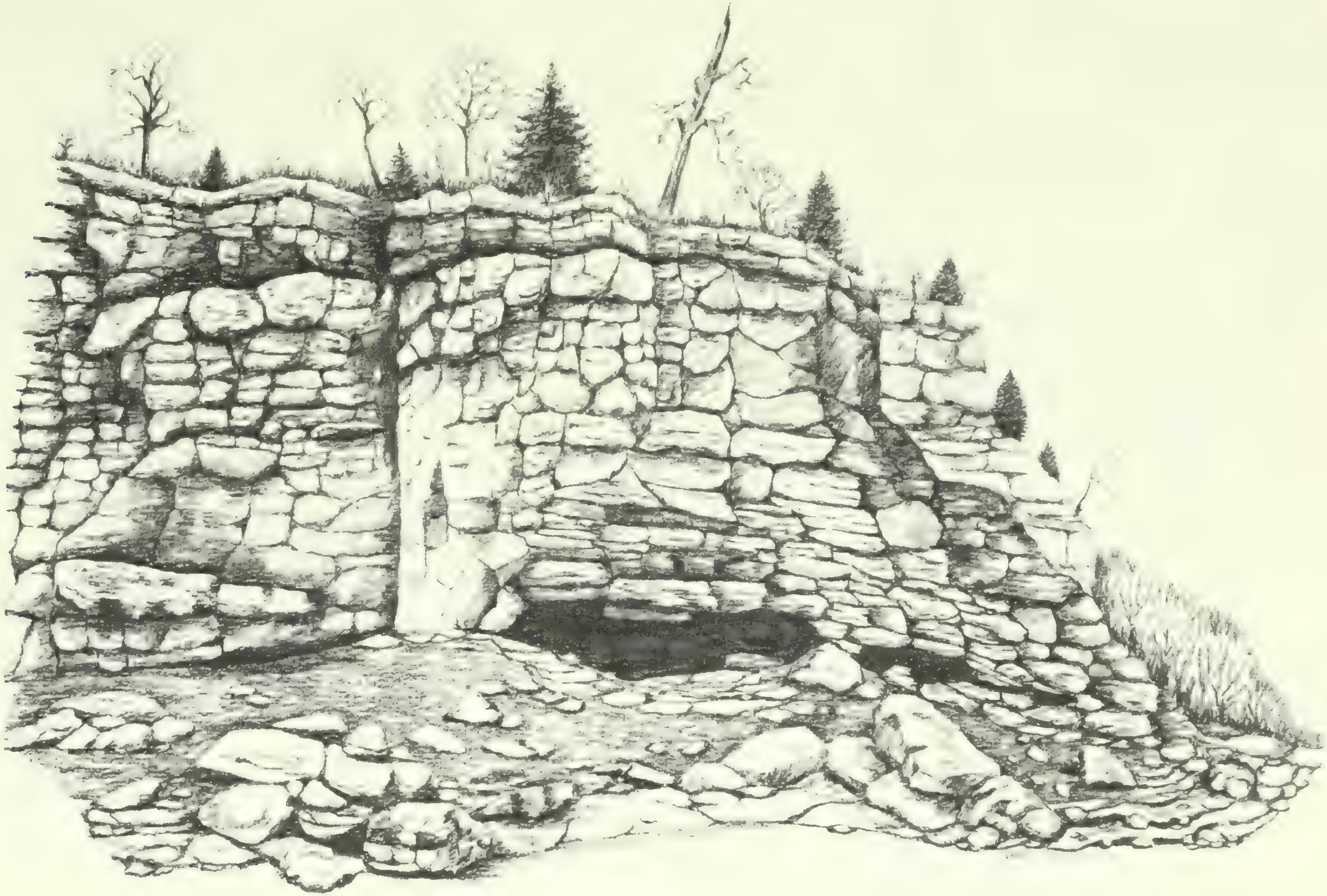
42 WATERHOLE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Killdeer	R	C		X						●			Rare in winter
Rough-winged Swallow	S	C						F		●			
Barn Swallow	S	C						F		●			Nests in buildings
Cliff Swallow	S	C						F		●			
Purple Martin	S	C				N		F		●			Cavity nester
Red-winged Blackbird˙	R	B		X					●	●			
Swamp Sparrow	W	D		F					●				
Song Sparrow	W	D		F					●				

[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)



51 — LIMESTONE BLUFF AND CAVE — Located along existing or old stream courses. Bluffs vary significantly by height, steepness, and associated plants.

Caves may be merely shallow overhangs to deep, long, underground caverns. The presence of water is important to animals.

51 LIMESTONE BLUFF AND CAVE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Turkey Vulture	R	C		X								●	Cliff nester
Black Vulture	S	D		X								●	Cliff nester
Golden Eagle	W	E		F							●		Perches on cliffs
Bald Eagle	W	E	F	F							●		Perches on cliffs
Peregrine Falcon	W	E						F			●		Historical nester
Merlin	W	E						F			●		Perches on cliffs
Rock Dove	R	C		X					●				Nests on buildings and cliffs
Great Horned Owl	R	D		F							●		Cliff nester
Barred Owl	R	D		F							●		Cliff nester
Eastern Phoebe	S	C		N				F		●			Nests in buildings, bridges, cliffs, etc
Bank Swallow	S	C		N				F		●			Mud bank nester
Rough winged Swallow	S	C		N				F		●			Cliff nester
Cliff Swallow	S	C		N				F		●			Cliff nester

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N), Both Forage and Nest in same level (X)

52 — FARMYARD OR TOWN RESIDENCE — A small area or lot containing a house and some — but not necessarily all — of the following: trees, shrubs, lawn, flower garden, fence, hedge, barn, roadway, bird feeders, and nesting boxes.

52 FARMYARD OR TOWN RESIDENCE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Sharp-shinned Hawk	R	E				N		F			●		
Red-tailed Hawk	R	C		F		N					●		
Merlin	W	E						F			●		
American Kestrel	R	D		F		N		F			●		Cavity nester
Bobwhite	R	C		X					●	●			
Killdeer	R	C		X						●			Bare ground areas
Rock Dove	R	B		F					●				Nests on buildings
Mourning Dove	R	C		F	N	N			●				
Yellow billed Cuckoo	S	C			X	X				●			
Black-billed Cuckoo	S	E			X	X				●			
Barn Owl	R	E		F		N					●		Cavity or building nester
Screech Owl	R	D		F		N					●		Cavity nester
Saw-whet Owl	W	D		F							●		
Whip poor-will	S	C		N				F		●			
Common Nighthawk	S	B		N				F		●			Nests on ground or buildings
Chimney Swift	S	B						F		●			Nests in buildings
Ruby throated Hummingbird	S	D		F	X							●	
Common Flicker	R	C		F		N				●			Cavity excavator
Pileated Woodpecker	R	D				N	F			●			Needs large snags
Red bellied Woodpecker	R	C				N	F			●			Cavity excavator

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A), Moderately Abundant (B) Common (C), Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F) Nest (N) Both Forage and Nest in same level (X)

52 FARMYARD OR TOWN RESIDENCE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Red-headed Woodpecker	R	C				N	F			●			Cavity excavator
Yellow-bellied Sapsucker	W	D					F					●	Cavity user
Hairy Woodpecker	R	D				N	F			●			Cavity excavator
Downy Woodpecker	R	C				N	F			●			Cavity excavator
Eastern Kingbird	S	C				N		F		●			
Eastern Phoebe	S	C						F		●			Nests on buildings, bridges, etc
Horned Lark	R	D		X					●				
Barn Swallow	S	C						F		●			Nests on buildings
Purple Martin	S	C						F		●			Nests in birdhouses
Blue Jay	R	B		F	X	X			●	●			
Common Crow	R	C		F		N			●	●			
Carolina Chickadee	R	C				X				●			Cavity nester
Tufted Titmouse	R	C				X				●			Cavity nester
White-breasted Nuthatch	R	C				N	F		●	●			Cavity nester
Brown Creeper	W	D					F			●			
House Wren	S	B				F	N			●			Cavity nester (town)
Winter Wren	W	D				F	F			●			
Bewick's Wren	S	C				F	N			●			Cavity nester (farm)
Carolina Wren	R	D		F	X					●			Cavity nester
Mockingbird	R	B			X				●	●			

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[1] Residence Permanent Resident (R) Summer Resident (S), and Winter Resident (W)

[2] Abundance Abundant (A) Moderately Abundant (B) Common (C) Uncommon (D) Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N) Both Forage and Nest in same level (X)

52 FARMYARD OR TOWN RESIDENCE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Gray Catbird	S	C			X					●			
Brown Thrasher	R	C			X				●	●			Rare in winter
American Robin	R	C		F		N			●	●			Eat berries in winter
Eastern Bluebird	R	D		F		N				●			Cavity nester
Cedar Waxwing	R	D			F	N			●				More common in winter
Loggerhead Shrike	R	C		F	N			F		●	●		
Starling	R	A		F		N			●	●			Cavity nester, prefers buildings
Warbling Vireo	S	C				X				●			
Yellow rumped Warbler	W	D				F			●	●			
House Sparrow	R	A		F		N			●	●			Cavity nester, prefers buildings
Red-winged Blackbird	R	B		X					●	●			
Orchard Oriole	S	C			N	X				●			
Northern Oriole	S	C				X				●			
Rusty Blackbird	W	D		F					●				
Brewer's Blackbird	W	D		F					●				
Common Grackle	R	B		F	N				●	●			
Brown headed Cowbird	R	B		F	N	N			●	●			Parasitic nester
Cardinal	R	B			X				●				
Rose breasted Grosbeak	S	D			N	F			●	●			Northern Ozarks only
Evening Grosbeak	W	D		F					●				

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

52 FARMYARD OR TOWN RESIDENCE

Bird Species	Residence[1]	Abundance[2]	Forage and Nest Level[3]						Primary Foods				Notes
			WATER	HERB	SHRUB	TREE	BARK	AIR	SEEDS	BUGS	PREY	OTHER	
Purple Finch	W	D				F			●				
Pine Siskin	W	D				F			●				
American Goldfinch	R	C		X					●	●			
Dark-eyed Junco	W	B		F					●				
Tree Sparrow	W	D		F					●				
Chipping Sparrow	S	C		F	N				●	●			
White-throated Sparrow	W	C		F					●				
Song Sparrow	R	D		X					●	●			

[1] Residence: Permanent Resident (R), Summer Resident (S), and Winter Resident (W)

[2] Abundance: Abundant (A), Moderately Abundant (B), Common (C), Uncommon (D), Extremely Rare or Endangered (E)

[3] Forage (F), Nest (N), Both Forage and Nest in same level (X)

	Page number																									
	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
	Habitat number																									
Species	01	02	03	04	05	06	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	41	42	51	52
Great Blue Heron																							x			
Green Heron																							x			
Great Egret																							x			
Canada Goose	x			x																						
Mallard	x																						x			
Wood Duck																							x			
Common Goldeneye																							x			
Hooded Merganser																							x			
Turkey Vulture	x	x	x	x	x	x		x		x	x	x	x					x	x			x	x		x	
Black Vulture	x			x	x			x		x	x	x										x	x		x	
Goshawk																		x				x				
Sharp-shinned Hawk								x	x	x						x	x	x			x	x	x			x
Cooper's Hawk								x	x	x						x		x			x	x	x			
Red-tailed Hawk	x	x	x	x	x	x	x	x	x	x	x	x						x					x			x
Red-shouldered Hawk																		x				x	x			
Broad-winged Hawk											x	x				x	x	x			x	x	x			
Rough-legged Hawk	x	x	x	x	x					x																
Golden Eagle	x				x					x													x		x	

Locator table for bird species associated with various habitats on the Ozark Plateau

	Page number																									
	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
	Habitat number																									
Species	01	02	03	04	05	06	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	41	42	51	52
Bald Eagle																							x		x	
Marsh Hawk	x			x	x	x																				
Osprey																							x			
Peregrine Falcon																									x	
Merlin																									x	x
American Kestrel	x	x	x	x	x	x		x	x	x								x				x	x			x
Ruffed Grouse									x				x	x	x	x	x						x			
Bobwhite	x	x	x	x	x	x	x	x	x	x									x							x
Greater Prairie Chicken					x																					
Turkey			x		x				x		x					x	x	x			x	x				
Killdeer	x	x		x	x						x													x		x
American Woodcock						x	x																x			
Upland Sandpiper				x	x																					
Spotted Sandpiper																							x			
Herring Gull																							x			
Ring-billed Gull																							x			
Rock Dove	x																								x	x
Mourning Dove	x	x	x	x	x	x	x	x	x	x	x	x	x						x				x			x

Page number	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
Habitat number	01	02	03	04	05	06	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	41	42	51	52
Species																										
Yellow-billed Cuckoo							x	x	x	x		x			x	x	x	x			x	x	x			x
Black-billed Cuckoo							x	x	x	x						x	x	x					x			x
Roadrunner											x	x														
Barn Owl										x								x								x
Screech Owl										x		x				x		x			x	x	x			x
Great Horned Owl										x						x		x			x	x	x		x	
Barred Owl								x		x						x		x			x	x	x		x	
Long-eared Owl																					x	x				
Short-eared Owl					x	x																				
Saw-whet Owl												x						x		x	x	x				x
Chuck-will's-widow										x		x				x		x		x	x		x			
Whip-poor-will									x	x	x	x			x	x		x			x	x	x			x
Common Nighthawk											x								x							x
Chimney Swift																		x				x				x
Ruby-throated Hummingbird			x			x	x	x	x	x			x						x				x			x
Belted Kingfisher																							x			
Common Flicker							x	x	x	x								x	x			x	x			x
Pileated Woodpecker									x							x	x	x			x	x	x			x

Locator table for bird species associated with various habitats on the Ozark Plateau

	Page number																									
	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
	Habitat number																									
Species	**01**	**02**	**03**	**04**	**05**	**06**	**11**	**12**	**13**	**14**	**15**	**16**	**21**	**22**	**23**	**24**	**25**	**26**	**31**	**32**	**33**	**34**	**41**	**42**	**51**	**52**
Red-bellied Woodpecker								x	x	x					x	x	x	x			x	x	x			x
Red-headed Woodpecker							x	x	x	x					x	x		x				x	x			x
Yellow-bellied Sapsucker									x	x								x	x		x	x	x			x
Hairy Woodpecker							x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x			x
Downy Woodpecker							x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x			x
Red-cockaded Woodpecker																						x				
Eastern Kingbird	x	x	x	x	x		x	x	x	x	x												x			x
Scissor-tailed Flycatcher			x	x	x		x	x		x																
Great Crested Flycatcher										x		x				x	x	x				x	x			
Eastern Phoebe								x	x	x								x					x		x	x
Acadian Flycatcher																	x	x					x			
Eastern Wood Pewee								x	x	x		x				x	x	x			x	x	x			
Horned Lark	x	x	x	x	x						x															x
Tree Swallow																							x			
Bank Swallow																							x		x	
Rough-winged Swallow	x	x	x	x	x	x																	x	x	x	
Barn Swallow	x	x	x	x	x	x																		x		x

	Page number																									
	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
	Habitat number																									
Species	**01**	**02**	**03**	**04**	**05**	**06**	**11**	**12**	**13**	**14**	**15**	**16**	**21**	**22**	**23**	**24**	**25**	**26**	**31**	**32**	**33**	**34**	**41**	**42**	**51**	**52**
Cliff Swallow	x	x	x	x	x	x																		x	x	
Purple Martin	x	x	x	x	x	x																		x		x
Blue Jay							x	x	x	x	x	x		x	x	x	x	x		x	x	x	x			x
Common Crow	x	x	x	x	x			x	x	x						x		x	x		x	x	x			x
Carolina Chickadee							x	x	x	x	x	x			x	x	x	x			x	x	x			x
Tufted Titmouse								x	x	x	x	x			x	x	x	x		x	x	x	x			x
White-breasted Nuthatch								x	x	x					x	x	x	x		x	x	x	x			x
Red-breasted Nuthatch																				x	x	x				
Brown-headed Nuthatch																				x	x	x				
Brown Creeper															x	x	x	x		x	x	x	x			x
House Wren						x	x	x	x	x								x								x
Winter Wren																	x	x		x	x	x	x			x
Bewick's Wren						x	x	x	x	x													x			x
Carolina Wren						x	x	x	x	x			x				x	x			x	x	x			x
Mockingbird							x	x	x	x		x											x			x
Gray Catbird							x	x	x	x		x	x	x					x				x			x
Brown Thrasher						x	x	x	x	x		x	x	x				x	x			x	x			x
American Robin								x	x	x		x											x			x

Locator table for bird species associated with various habitats on the Ozark Plateau

Page number	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
Habitat number																										
Species	01	02	03	04	05	06	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	41	42	51	52
Wood Thrush														x		x	x	x					x			
Hermit Thrush												x			x		x	x					x			
Eastern Bluebird								x	x	x								x								x
Blue-gray Gnatcatcher							x	x	x	x		x			x	x	x	x					x			
Golden-crowned Kinglet										x		x								x	x	x	x			
Ruby-crowned Kinglet										x		x								x	x	x	x			
Cedar Waxwing							x		x			x						x					x			x
Loggerhead Shrike						x		x	x	x																x
Starling																										x
White-eyed Vireo						x	x	x	x	x			x	x					x							
Bell's Vireo						x	x																			
Yellow-throated Vireo								x	x	x						x	x	x			x	x	x			
Red-eyed Vireo															x	x	x	x			x	x	x			
Warbling Vireo															x	x	x	x					x			x
Black-and-white Warbler							x	x	x	x	x	x	x	x	x	x	x	x			x	x	x			
Prothonotary Warbler																							x			
Swainson's Warbler																							x			
Worm-eating Warbler														x		x	x	x					x			

Locator table for bird species associated with various habitats on the Ozark Plateau

	Page number																									
	2	4	6	8	10	12	14	18	22.	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
	Habitat number																									
Species	01	02	03	04	05	06	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	41	42	51	52
Blue-winged Warbler							x		x	x				x	x					x						
Bachman's Warbler																							x			
Northern Parula Warbler										x							x	x			x	x	x			
Yellow-Warbler							x																x			
Yellow-rumped Warbler						x	x	x	x	x		x	x	x	x			x				x	x			x
Cerulean Warbler															x			x					x			
Yellow-throated Warbler																		x			x		x			
Chestnut-sided Warbler										x			x													
Pine Warbler																					x	x				
Prairie Warbler							x	x	x		x	x	x						x							
Ovenbird															x	x	x	x					x			
Louisiana Waterthrush																							x			
Kentucky Warbler														x		x	x	x					x			
Common Yellowthroat						x	x			x			x						x				x			
Yellow-breasted Chat						x	x	x	x	x			x	x					x	x						
Hooded Warbler															x	x	x	x					x			
American Redstart															x	x	x						x			
House Sparrow																										x

Locator table for bird species associated with various habitats on the Ozark Plateau

Page number	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
Habitat number	01	02	03	04	05	06	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	41	42	51	52
Species																										
Eastern Meadowlark	x	x	x	x	x	x		x																		
Red-winged Blackbird	x	x	x	x	x																		x	x		x
Orchard Oriole							x		x	x								x					x			x
Northern Oriole								x	x									x					x			x
Rusty Blackbird			x			x	x	x	x														x			x
Brewer's Blackbird	x	x	x			x	x	x	x														x			x
Common Grackle	x	x	x					x	x	x								x								x
Brown-headed Cowbird				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x
Scarlet Tanager																x	x	x					x			
Summer Tanager														x	x	x	x	x					x			
Cardinal						x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x			x
Rose-breasted Grosbeak										x																x
Blue Grosbeak						x	x	x	x	x	x	x	x						x							
Indigo Bunting	x					x	x	x	x	x	x	x	x	x									x			
Painted Bunting							x			x		x														
Dickcissel	x	x	x	x	x	x		x																		
Evening Grosbeak							x			x										x						x
Purple Finch							x	x	x	x								x				x				x

Page number	2	4	6	8	10	12	14	18	22	26	30	32	34	36	38	40	42	44	48	50	52	54	58	62	64	66
Habitat number Species	01	02	03	04	05	06	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	41	42	51	52
Pine Siskin							x		x	x						x	x	x		x	x	x				x
American Goldfinch		x	x	x	x	x	x	x	x	x		x	x						x				x			x
Rufous-sided Towhee						x	x	x	x	x			x	x					x				x			
Savannah Sparrow	x		x		x	x																				
Grasshopper Sparrow			x	x	x																					
Lark Sparrow		x	x	x	x						x	x	x						x							
Bachman's Sparrow						x		x			x		x						x							
Dark-eyed Junco	x	x		x	x	x				x			x						x							x
Tree Sparrow	x	x				x	x	x	x	x			x						x							x
Chipping Sparrow								x	x	x								x								x
Field Sparrow						x	x	x	x	x	x	x	x						x							
Harris Sparrow		x					x			x													x			
White-crowned Sparrow	x	x	x	x	x	x	x	x	x	x																
White-throated Sparrow		x	x	x	x	x	x	x	x	x			x	x					x							x
Fox Sparrow	x	x	x	x	x	x	x	x	x	x			x	x					x							
Swamp Sparrow		x	x	x	x	x	x	x		x			x						x				x	x		
Song Sparrow	x	x	x	x	x	x	x	x		x			x	x					x				x	x		x
Number of Species	32	29	31	32	36	43	53	64	64	79	26	38	30	22	26	39	38	67	29	19	39	50	101	8	13	68

BIRDING "HOTSPOTS"
Ozark Rivers

There are more than 2,200 miles of canoeable water in the Ozark region. This is an area of big springs; clean, clear rivers; rugged forested hills; friendly people; and rich and diverse birdlife. The Ozark rivers, especially during the summer, are tame enough for family floaters. The roads normally follow the ridges, instead of the river valleys, and cross the rivers infrequently. All you have to do is launch a canoe or john boat on one of the many streams for a day, week, or month of serenity, fellowship, fishing, and birding. Scattered throughout the area are canoe rentals. The region also includes much public land — the Mark Twain National Forest, the Ozark National Scenic Riverways, and various State Parks.

Birding by canoe can be productive in any season — even winter when bald eagles are commonly seen along the larger rivers. To see the maximum number of species, go during the last two weeks in April and the first two weeks in May.

The best birding technique is to go slowly and stop often to look and listen. Birds generally are not frightened by a canoe if quick movements and loud noises are avoided. Birdlife along Ozark rivers is exceedingly rich because wooded streamsides and bottomland hardwood habitat (41) has so many trees and shrubs of different heights and sizes. You also encounter *cultivated fields* (01), *pastures* (04), *old fields* (06, 11, 12, 13), an abundance of *edge* (14), many different forest conditions, and specialized habitats such as *cliffs, bluffs,* and *caves* (61). The more habitats you search, the more species of birds you are likely to encounter.

Water attracts green herons, wood ducks, Louisiana waterthrushes, and belted kingfishers. And the productive *streamside* habitat produces an abundance of rodents and reptiles that are food items for raptors such as ospreys and red-shouldered hawks that are rarely seen in other habitats.

A few species such as the acadian flycatcher, Carolina wren, and yellow warbler prefer *streamside* habitat to all other types available in the Ozarks. In fact, *streamside* habitat is the best place in the Ozark to see and hear warblers in general. Two of the many species, Swainson's and Bachman's, are considered endangered and the Bachman's may be extinct. The Swainson's warbler selects canebreaks for nesting habitat. Canebreaks along Ozark streams are probably reduced to a size too small to support Swainson's warblers. The beautiful songs of the cerulean, yellow, and prothonotary warblers may compensate for the rarity of other species.

Sycamore, gum, and ash trees along Ozark streams are prone to heartrot and form nesting cavities for 7 woodpecker species. Including both the cavity excavators, and the secondary cavity users, 20 cavity nesting species can be observed during the summer months. The pileated woodpecker is the most spectacular of this group. This nearly crow-sized bird has a red, white, and black head pattern and a loud penetrating voice. The call, which seems to say 'Kuk-Kuk-Kuk-Kuk-Kuk", is louder, faster, and more irregular than the similar common flicker call.

Glade Top Trail

The Glade Top Trail lies southeast of Springfield, Missouri, on the Ava District of the Mark Twain National Forest. To reach the Glade Top Trail from Ava, take Missouri Highway 5 south for 5 miles, then turn right (continuing south) onto County Route A. After 2.5 miles, turn left onto a gravel road for about 2 miles to the forest boundary and the beginning of Forest Service Road 162. Just inside the boundary is a marker and map noting the official beginning of the trail. Continue following Forest Service Road 162 until it meets FS 147, then follow 147 to Missouri Highway 125.

The trail is approximately 15 miles of all-weather, all-season, gravel road traversing a variety of vegetation types. Six scenic view pulloffs and one picnic area are maintained by the USDA Forest Service. Oak-hickory forests intermixed with glades dominate the area. The glades are forest openings characterized by shallow soil, rocky outcrops, and prairie vegetation. Flowers are abundant among the prairie grasses and the species in bloom change constantly through the growing season. This adds immeasurable pleasure to the birding experience. Several woody plant species grow in the glades, but redcedar *(Juniperus virginiana)* is the most common, varying from a few scattered trees to extremely dense stands. This wide range in groundcover increases the variety of bird habitats found along the trail.

The glades are interesting at all times, but the best birding is during the breeding season (late May and June). The most common nesting species on the open glades are the prairie warbler and the field sparrow. Bachman's sparrow occurs sporadically. Indigo buntings, mourning doves, blue-gray gnatcatchers, and rufous-sided towhees occur in light to

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medium cover, while the dense redcedar cover contains many species which normally occur in the oak-hickory forest. The great crested flycatcher, ovenbird, black-and-white warbler, and Carolina chickadee are some examples. Turkey vultures are constantly in view, and black vultures are occasionally sighted.

The openness of the Glade Top Trail allows for observation of broad-winged hawks in the summer and an occasional golden eagle in the winter. At dusk, the sounds of the area are dominated by whip-poor-will and some chuck-will's-widow calls, and the hoot of an occasional barred owl. The adjacent forest is slow-growing and provides good habitat for many of the cavity nesters — the pileated woodpecker being one of the most conspicuous species. Caney Picnic Area is the best spot to see glade species such as prairie warbler and Bachman's sparrow. The Arkansas View Turnout is the best for forest species.

One special feature of the glades is the influence of the desert southwest and southern animal life which reach their northeastern limits of distribution here. The most conspicuous southwestern bird is the roadrunner; however, the painted bunting occurs near Branson, Missouri, less than 30 air miles southwest, and may possibly live in the Glade Top Trail area also. Other interesting creatures include the collared lizard *(Crotaphytus collaris)*, scorpions, and tarantulas.

The Ava, Missouri, Chamber of Commerce and the USDA Forest Service sponsor a week of Glade Top Trail tours and a Sunday barbeque each year in October. Food and lodging are available at Ava, ten miles away.

Anyone interested in combining some autumn birding with a tour of the Ozarks' fall colors should visit or write the District Ranger, Mark Twain National Forest, Ava, Missouri, 65608.

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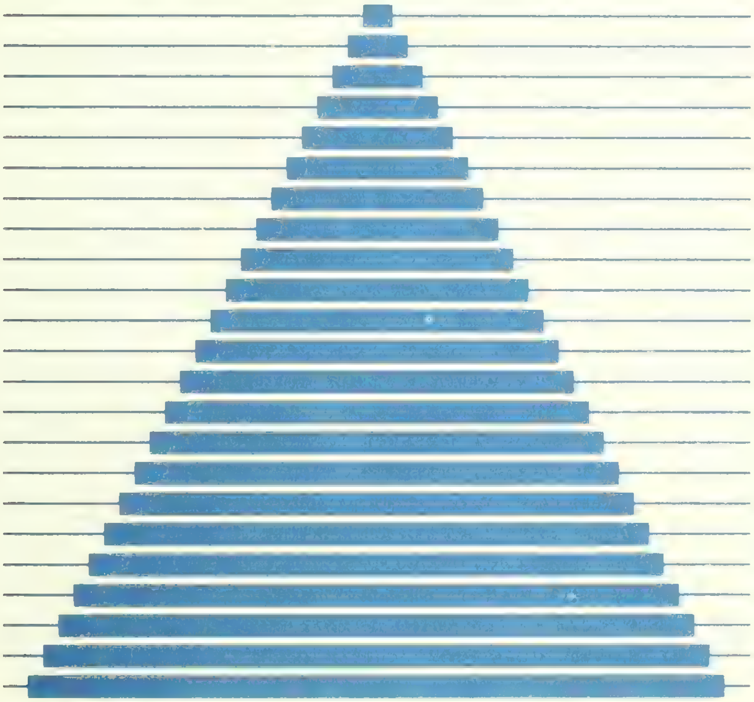
SIMULATING TIMBER MANAGEMENT IN LAKE STATES FORESTS



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1981

SIMULATING TIMBER MANAGEMENT IN LAKE STATES FORESTS[1]

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Research Forester

Tree growth models are useful tools in projecting the growth of forest stands. If a growth model is programmed for use on a computer, the growth of a stand can be quickly and inexpensively projected. Rapid and inexpensive projections are important in a regional analysis, where there are many stands to evaluate. However, unless tree cutting can be simulated, the model is limited to predicting what will happen to unmanaged stands.

A Stand and Tree Evaluation and Modeling System (STEMS) has been developed at the North Central Forest Experiment Station (Leary 1979, Leary *et al.* 1979)[2,3] for the Lake States region (Michigan, Minnesota, and Wisconsin) of the United States. This computerized system simulates the changes in the forest as trees grow, die and are cut. This paper describes the part of the system, the management subsystem, that simulates tree cutting and explains how it can be modified to simulate many different tree cutting strategies.

To better understand the management subsystem, a brief description of STEMS is needed. STEMS is designed to grow any mixture of tree species or sizes in the Lake States. Growth equations were developed for 27 Lake States' species or groups of species. The equations for different species differ only by having different numerical coefficients. The stand that will be grown is represented in the computer by a tree list containing tree species, diameters, and crown ratio codes and values for stand characteristics. If available, tree quality codes are also used. The stand characteristics are age, site index, basal area, number of trees, and average diameter. These characteristics provide the only information available for growing trees, deciding on a management prescription, and selecting trees to cut. As trees grow, die, and are cut the tree list is altered (fig. 1).

There are two approaches which could be used in the management subsystem to simulate tree cutting. One is to have the *user* prescribe and implement cutting; the other is to have the *computer* prescribe and implement cutting. The first approach is impractical when hundreds of stands must be evaluated, as is the case when using STEMS for a regional analysis. Therefore, the second approach is used. However, before the computer can prescribe and implement cutting it must be told what to do. The rest of this paper explains how the user tells the computer how to prescribe and implement cutting on the stands it *will be* encountering.

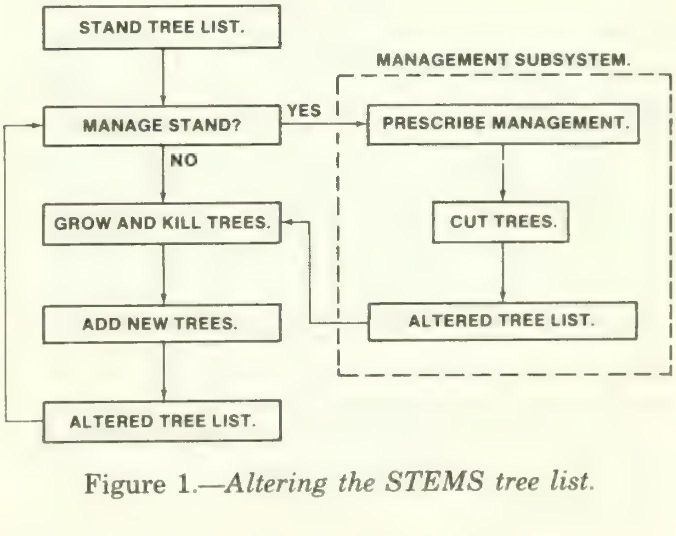

Figure 1.—*Altering the STEMS tree list.*

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[1] A major portion of this work was conducted under a cooperative agreement between the North Central Forest Experiment Station and the College of Forestry, University of Minnesota, St. Paul, Minnesota.

[2] *Belcher, David M., Margaret Holdaway, and Gary Brand. (In preparation.) A description of STEMS.*

[3] *STEMS was designed to be part of an overall Forest Resource Evaluation Program (FREP). Currently only the tree growth model STEMS exists. A prior accronym for STEMS was FREP78.*

The timber management guides for the following cover types form the basis for the rules on deciding how cutting should be done:

Cover type	Source
Jack pine	Benzie 1977a
Red pine	Benzie 1977b
White pine	USDA For. Serv. 1958
Spruce-fir	USDA For. Serv. 1967
Black spruce	Johnston 1977a
Mixed swamp conifers	Johnston 1977b
Northern white-cedar	Johnston 1977b
Tamarack	Johnston[4]
Oak-hickory	Sander1977
Aspen	Perala1977
Paper birch	Tubbs 1977, Godman[4], Perala[4]
Lowland hardwoods	Godman[4]
Northern hardwoods	Tubbs 1977, Godman[4]
Understocked	Benzie[4]

TIMBER MANAGEMENT SIMPLIFIED

Timber management guides recommend prescriptions for a stand on the basis of research results, experience, and silvical knowledge. However, the prescriptions are only guidelines. In practice the forest manager in the woods integrates the complex set of factors which affect the growth of a stand. These factors are such things as: potential for disease, insect, or physical damage; species composition; spacing of the trees; amount of inhibiting vegetation; and type of soil. The manager may modify the prescription from the management guide to better reflect these local conditions.

To simulate the skill and subjective judgement that the manager uses to integrate these many factors would be complicated. It would also require a lot of information. Therefore simplifying assumptions were made in developing the management subsystem. Two basic assumptions are: trees are uniformly spaced; and shrubs and herbaceous plants are unimportant. In addition each guide may have its own particular assumptions (see Appendix A).

The management subsystem has two tasks: (1) to *prescribe* or determine a management prescription; and (2) to *implement* the prescription by designating which, if any, trees to cut. These two tasks are described in the following sections.

DETERMINING THE MANAGEMENT PRESCRIPTION

The first step in constructing a computerized subsystem is to convert each management guide to a decision diagram. The diagram is much like a road with signs at each intersection indicating where the road goes. For example, a guide for jack pine might prescribe a clearcut at age 50 for stands with a site index greater than or equal to 60 (SI $\geq$ 60) and a clearcut at age 65 if the site index is less than 60 (SI < 60). Figure 2 converts this verbal statement to a decision diagram. At the first intersection go up if the site index is less than 60, and go down if it is not. Regardless of which branch is taken, age is considered next to determine if the prescription is "do nothing" or "clearcut". If the stand age is less than the prescribed clearcut rotation age, nothing is done. If the stand age is greater than or equal to the specified rotation age, a clearcut is prescribed. Usually management guides are more complex than this but the principle is the same.

Decision diagrams (Appendix A) were developed for the types listed in the previous tabulation. The lowland hardwood guide (fig. 3) is discussed below to show how it is used and how it can be changed to produce different prescriptions for the same stand condition.

In figure 3 tree cutting prescriptions are based on three stand characteristics: site index in feet (SI), stand age in years (Age), and basal area in square feet per acre (BA). These stand characteristics are used to decide which action to prescribe. At each decision point the stand's characteristics are compared to the decision values given by the management guides. These management guide values are called critical values. For this lowland hardwood guide the critical value for site index is 55. Stands

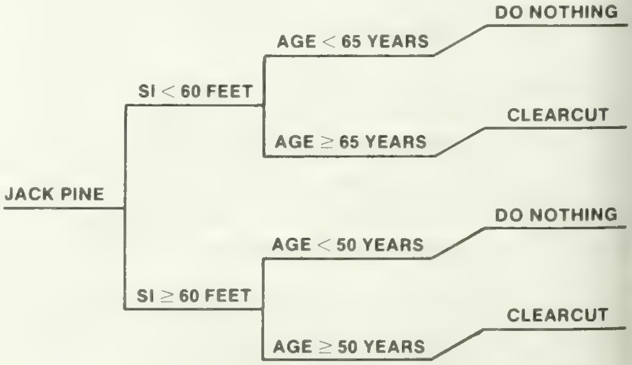

Figure 2.—*Diagram of a simple jack pine management guide.*

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[4] *Personal communications.*

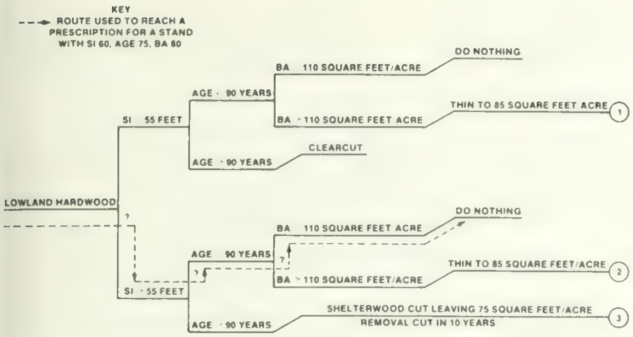
KEY
ROUTE USED TO REACH A PRESCRIPTION FOR A STAND WITH SI 60, AGE 75, BA 80
LOWLAND HARDWOOD
SI 55 FEET
AGE < 90 YEARS
BA 110 SQUARE FEET/ACRE
DO NOTHING
BA > 110 SQUARE FEET ACRE
THIN TO 85 SQUARE FEET ACRE
1
AGE > 90 YEARS
CLEARCUT
?
SI > 55 FEET
AGE 90 YEARS
?
BA 110 SQUARE FEET ACRE
?
DO NOTHING
BA > 110 SQUARE FEET/ACRE
THIN TO 85 SQUARE FEET/ACRE
2
AGE > 90 YEARS
SHELTERWOOD CUT LEAVING 75 SQUARE FEET/ACRE
REMOVAL CUT IN 10 YEARS
3

Figure 3.—*Example of how a lowland hardwood diagram is used.*

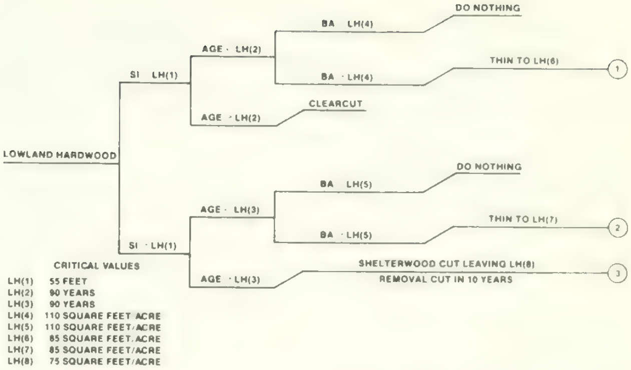

Figure 4.—*Generalized lowland hardwood diagram.*

with site indexes less than 55 follow a different prescription path than stands with a site index of 55 or higher. Similarly, the critical value for age is 90 and for basal area is 110. These critical values happen to be the same for each branch, but they may be different for some diagrams.

Now let's see how such a diagram is used to determine a cutting prescription. Suppose a lowland hardwood stand has these characteristics:

Site index - 60 feet at 50 years
Age - 75 years
Basal area - 80 square feet per acre.

To find the current prescription for this stand, the stand site index of 60 is compared with 55, the value at the first intersection. Since the site index is greater than 55 the lower path is taken. Next, the stand age of 75 years is compared with the value at the next intersection, 90 years, and top route is selected because the stand age is less than 90. Finally, the stand basal area of 80 square feet per acre is less than 110 so the prescription is "do nothing" (fig. 3).

Although this management guide may be very reasonable, local conditions might make another guide more useful, or a manager might like to explore the effect of several different management guides. A simple change in the diagram makes this kind of manipulation easy.

To make the diagram more general the critical values in figure 3 are replaced with symbols or variables which indicate that they may change (fig. 4). Ordinarily the variables will take on values that have been determined from published management guides. In figure 4 the critical value for the variable at the first intersection, LH(1), is 55. This is the same value that appeared in figure 3. If the listed critical values are used, the generalized diagram (fig. 4) and the specific diagram (fig. 3) produce the same prescription for any given stand.

The advantage of the generalized diagram is that it can be easily changed by the program user to simulate other management guides. Could a manager use this diagram for a guide that prescribes shelterwood cutting of all lowland hardwood stands, regardless of site, at age 70? Yes, by making two changes in the critical values. Change the critical values LH(1) to zero and LH(3) to 70 (fig. 5). Since all site indexes will be greater than zero, the upper path will never be used, and all stands will be routed to the lower path.

In the previous example, our stand has an age of 75, so according to this new guide it should be shelterwood cut. The new diagram prescribes this. Comparing the stand site index 60 with the critical value at the first intersection (LH(1) is now zero), shows we must take the lower path. Next, the age is greater than 70 (the critical value of LH (3)) so again the lower path is selected and the prescription is "shelterwood cut".

Many other lowland hardwood guides could be produced with this diagram. The limitation is that the structure of the diagram cannot be changed. This means that intersections are not added and other stand characteristics are unimportant. If a lowland hardwood guide recommends different prescriptions for three ranges of site index this diagram cannot be used. Neither can it be used for a guide that makes a prescription based on average diameter. In these cases a new diagram must be constructed and programmed.

Generalized diagrams for the other forest types are in Appendix A. They make prescriptions for various stand conditions, but this is only part of the task. To carry out the prescription the manager must mark the trees to be cut.

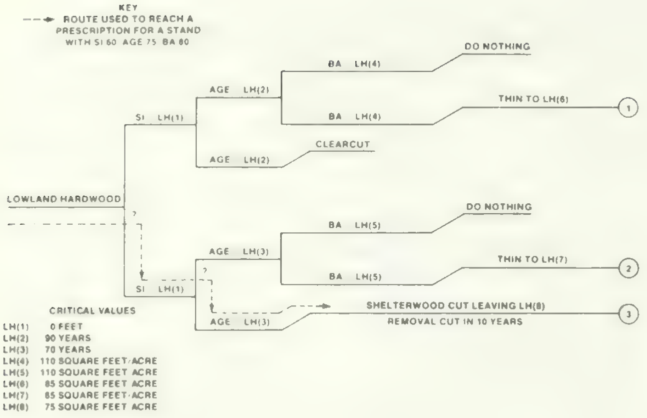

Figure 5.—*Modified lowland hardwood diagram.*

IMPLEMENTING THE PRESCRIPTION—DESIGNATING TREES TO BE CUT

For prescriptions like "clearcut" and "do nothing" all trees are either cut or left. A more interesting problem is what to do when only some of the trees are cut. Prescriptions in the latter category are indicated by a circled number in the diagrams.

The lowland hardwood guide has three prescriptions with circled numbers, two are "thin" and one is "shelterwood cut". For each of these prescriptions the manager must develop a marking rule that ranks the trees for cutting. A marking rule when thinning a lowland hardwood stand might be:

(1) first mark low quality trees;
(2) next mark elms from above (with the largest diameters cut first) to minimize the loss to Dutch elm disease;
(3) then mark from below the undesirable species; (cut the smallest diameter trees first);
(4) finally, mark from below the desirable species (black ash, red maple, yellow birch).

A method was developed to simulate marking rules like these.

The method involves selecting different combinations of removal procedures. The order of the removal procedures determines which is done first, second, and so forth. The procedures rank trees using the tree characteristics: species, diameter, crown ratio, and quality. In each of the nine procedures (table 1), different tree characteristics are used in ranking trees for cutting.

To simulate the marking rule just described for lowlands hardwoods, four removal procedures would be used. They are procedure codes 1, 5, 2, and 4. The first marks low quality trees. Number five thins from above (marks the largest diameter trees first) the specified species (which is elm for lowland hardwoods). The next procedure, number two, thins from below (marks the smallest diameter trees first the undesirable species. This procedure requires the desirable species to be listed. For this example they are black ash, red maple, and yellow birch. The last procedure (4) thins the desirable species from below Appendix B contains marking rules for all prescriptions in the management diagrams (Appendix A which end in a circled number.

Each removal procedure must have certain information supplied (table 1). A code is used by the program to determine the procedure and needed information. the code is a 13 digit number with the first digit indicating the procedure and the rest of the digits coded according to table 1. The codes that produce the previous marking rule are:

digit position	1	2	3	4	5	6	7	8	9	10	11	12	13	
	1	0	0	9	9	0	0	0	0	0	0	0	0	size of trees to cut 0 to 99
	5	0	0	9	9	1	5	0	0	0	0	0	0	species code for elm-15.
codes	2	0	0	9	9	1	1	1	4	1	6	0	0	code for black ash-11,
	4	0	0	9	9	1	1	1	4	1	6	0	0	red maple - 14, yellow birch - 16

If a manager did not mark trees smaller than 5 inches the third digit in each code would be replaced by a 5 Up to five removal procedures can be combined to simulate a marking rule. Even though tree spacing or other tree characteristics cannot be used, these removal procedures can be combined to produce many marking rules.

USING THE MANAGEMENT SUBSYSTEM

This management subsystem exists as subroutines within STEMS (Hahn and Brand 1979)[2]. So far they have been used in estimating the treatment opportunities existing on a national forest and on areas in Wisconsin and Minnesota. Inventory plots taken for statewide surveys were used as initial conditions The results were helpful in identifying which forest types needed treatment. In conjunction with the projection system, treatment needs were followed through time.

Table 1.— *Removal Procedures*

Procedure CODE	Procedure	Information needed for coding	Code Digit position	Code Value
1	Remove rough and rotten trees in designated size class unitl required BA is achieved. (Tree quality codes are needed for this procedure.)	Size class to remove.	1	1
			2-3	Lower diameter limit
			4-5	Upper diameter limit
			6-13	All zeros
2	Remove smallest trees of unspecified species until required BA is achieved.	Size class to remove, 4 species groups to leave.	1	2
			2-3	Lower diameter limit
			4-5	Upper diameter limit
			6-7, 8-9 10-11, 12-13	4 species group codes to leave
3	Remove largest trees of unspecified species until required BA is achieved.	Size class to remove, 4 species groups to leave.	1	3
			2-13	Same as 2
4	Remove smallest trees of specified species until required BA is achieved.	Size class to remove, 4 species groups to remove.	1	4
			2-3	Lower diameter limit
			4-5	Upper diameter limit
			6-7, 8-9 10-11, 12-13	4 species group codes to remove
5	Remove largest trees of specified species until required BA is achieved.	Size class to remove, 4 species groups to remove.	1	5
			2-13	Same as 4
6	Shelterwood cut leaving required BA (leave largest d.b.h, highest crown ratio trees).	Size class to remove, 4 species groups to favor.	1	6
			2-3	Lower diameter limit
			4-5	Upper diameter limit
			6-7, 8-9 10-11, 12-13	4 species group codes to favor
7	Reduce number of trees.	Number of trees to leave.	1	7
			2-5	Number of trees/ac to leave
			6-13	All zeros
8	Remove all overtopping.	Lower d.b.h of trees to remove.	1	8
			2-3	Lower d.b.h of trees to remove
			4-13	All zeros
9	Remove all trees of a certain size and species.	Size class to remove, 4 species groups to remove.	1	9
			2-13	Same as 4

Major variations in the diagrams can be created by setting the critical values to extremely large or small quantities. However, if a decision is desired about a variable not in the diagram a new diagram must be programmed. This is a relatively simple task for someone with moderate programming skills, provided the decision diagram is known. A second concern is that there is no provision for constraints on management within a property. All stands are treated according to the prescription. A definite need is to incorporate area or volume control within the system.

In summary, a computerized procedure for prescribing tree cutting for Lake States' timber types has been developed based upon published management guides. This management system is flexible and provides a means to analyze and assess the effect that various treatments will have on the timber resource in a particular area. Although the computer subroutines were written to be included in STEMS, they could be readily incorporated into other systems as well. To make management prescriptions the stand characteristics mentioned in Appendix A and species basal areas must be known. If the presciptions are to be implemented then a tree list must be available or another method of carrying out the prescription must be developed.

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APPENDIX A

Management Diagrams

Plot or stand description	Diagram number
Jack pine	1
Red pine	2
White pine	3
Spruce-fir	4
Black spruce	5
Mixed swamp conifers[5]	6
Northern white-cedar[5]	7
Tamarack	5
Oak-hickory	8
Aspen	9
Paper birch	10
Northern hardwood	11
Lowland hardwood	12
Understocked	13

Diagram numbers appear within squares. If a diagram ends with a number within a square, continue to that diagram to determine the management prescription. Numbers which appear within circles indicate that particular trees must be marked. These marking rules are described in Appendix B.

Description of Symbols in Management Diagrams

Symbol	Units	Description
Age	years	Stand age.
BA	square feet/acre	Basal area of all live trees on the plot.
BAPOLE	square feet/acre	Basal area of all live trees with d.b.h. greater than or equal to 5 inches and less than 10 inches.
BASAP	square feet/acre	Basal area of all live trees with d.b.h. less than 5 inches
BASAW	square feet/acre	Basal area of all live trees with d.b.h. greater than or equal to 10 inches.
$\overline{\text{DBH}}$	inches	Arithmetic mean d.b.h. of live trees on the plot.
ICOMP	—	Species composition code.
NT	trees/acre	Number of live trees on plot.
QMDBH[6]	inches	D.b.h. of tree of average basal area.
SI	feet	Plot site index.
$<$		as in $a<b$— a is less than b
$\leq$		as in $a\leq b$— a is less than or equal to b
$>$		as in $a>b$— a is greater than b
$\geq$		as in $a\geq b$— a is greater than or equal to b

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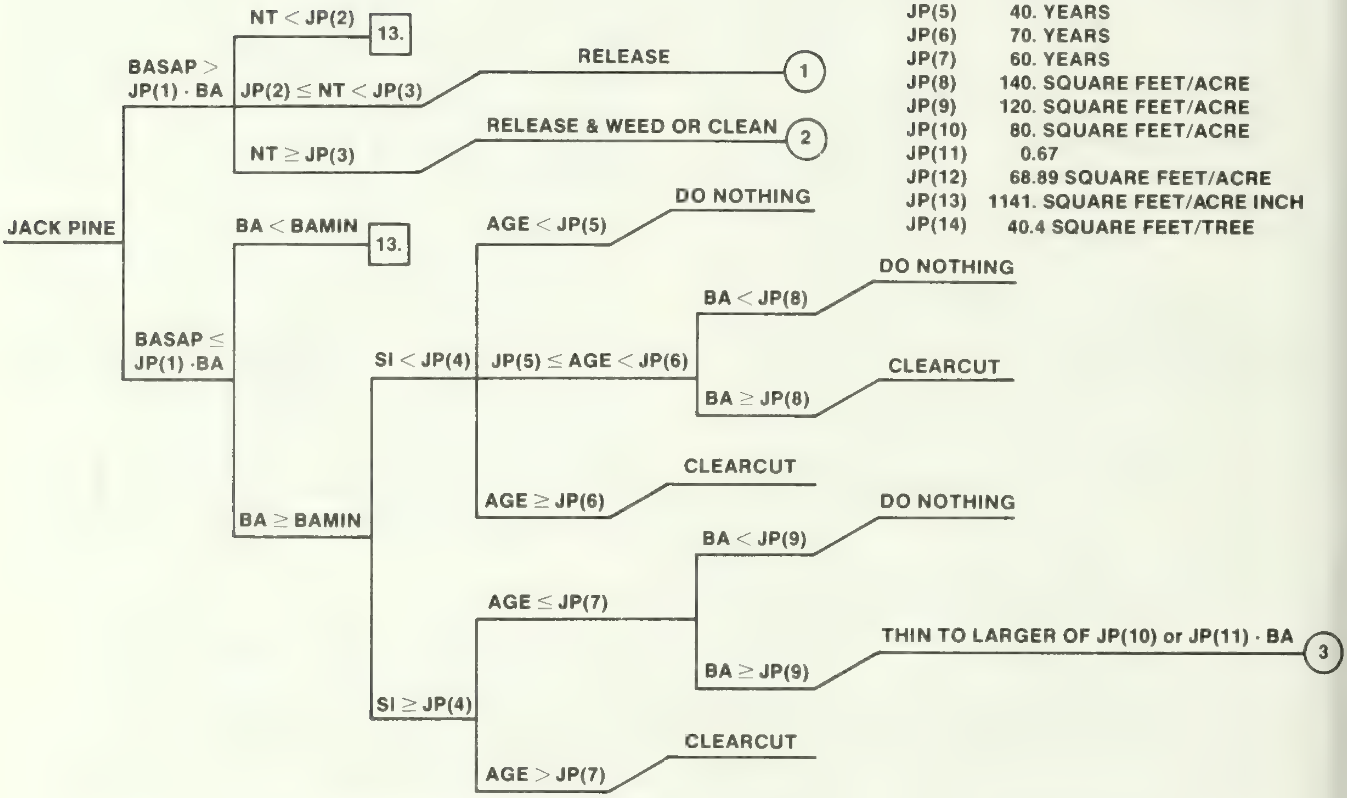
[5] *The final harvest is a three strip system. The first two strips are clearcut and on better sites the last strip is shelterwood cut. In STEMS, three plots of the same site class and at rotation age are needed to simulate the three strip system. The first plot is clearcut, the second is clearcut after a 10-year wait, and the third is clearcut or shelterwood cut after a 20-year wait.*

[6] $$\text{QMDBH} = \sqrt{\frac{\text{BA}}{.005454 \times \text{NT}}}$$

1.

	CRITICAL VALUES
JP(1)	0.5
JP(2)	400. TREES/ACRE
JP(3)	2000. TREES/ACRE
JP(4)	60. FEET
JP(5)	40. YEARS
JP(6)	70. YEARS
JP(7)	60. YEARS
JP(8)	140. SQUARE FEET/ACRE
JP(9)	120. SQUARE FEET/ACRE
JP(10)	80. SQUARE FEET/ACRE
JP(11)	0.67
JP(12)	68.89 SQUARE FEET/ACRE
JP(13)	1141. SQUARE FEET/ACRE INCH
JP(14)	40.4 SQUARE FEET/TREE

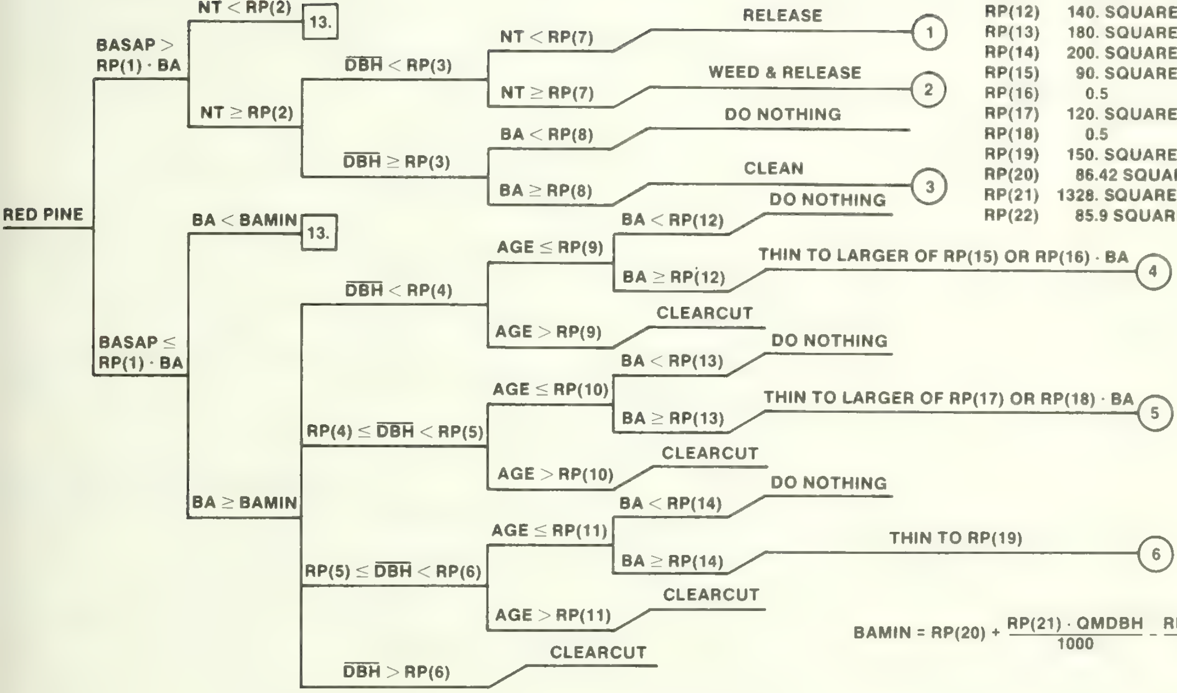


$$\text{BAMIN} = \text{JP}(12) + \frac{\text{JP}(13) \cdot \text{QMDBH}}{1000} - \frac{\text{JP}(14) \cdot \text{NT}}{1000}$$

Jack Pine Objectives and Assumptions

1. Maintain jack pine.
2. Manage for timber, particularly large products if possible.
3. Trees are uniformly distributed in the even-aged stand.
4. There is a low risk of loss from damaging agents.
5. Conditions are appropriate for using the clearcut silvicultural system.

2.



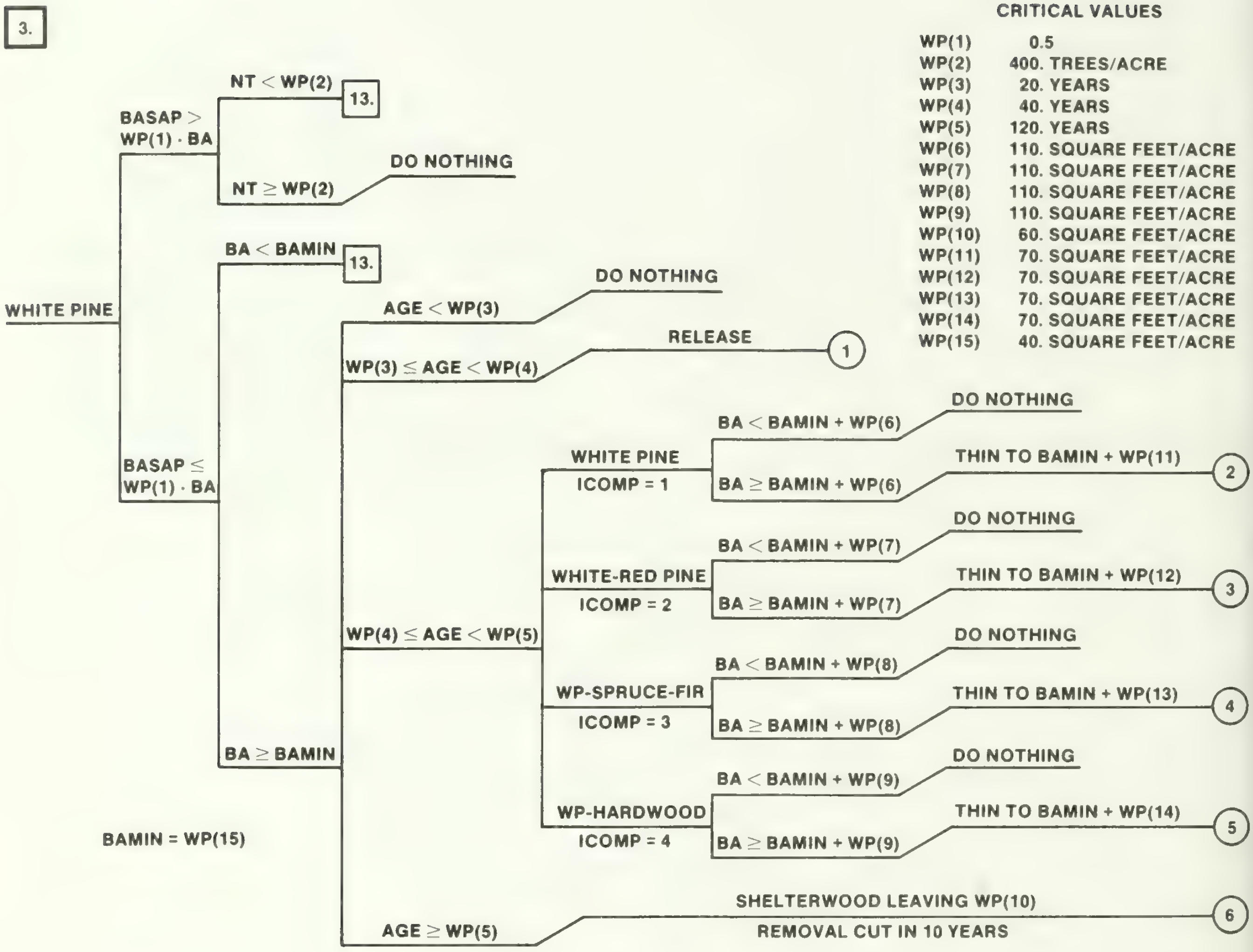
CRITICAL VALUES

RP(1)	0.5
RP(2)	400. TREES/ACRE
RP(3)	2. INCHES
RP(4)	9. INCHES
RP(5)	15. INCHES
RP(6)	20. INCHES
RP(7)	2000. TREES/ACRE
RP(8)	160. SQUARE FEET/ACRE
RP(9)	160. YEARS
RP(10)	140. YEARS
RP(11)	120. YEARS
RP(12)	140. SQUARE FEET/ACRE
RP(13)	180. SQUARE FEET/ACRE
RP(14)	200. SQUARE FEET/ACRE
RP(15)	90. SQUARE FEET/ACRE
RP(16)	0.5
RP(17)	120. SQUARE FEET/ACRE
RP(18)	0.5
RP(19)	150. SQUARE FEET/ACRE
RP(20)	86.42 SQUARE FEET/ACRE
RP(21)	1328. SQUARE FEET/ACRE INCH
RP(22)	85.9 SQUARE FEET/TREE

$$\mathrm{BAMIN} = \mathrm{RP}(20) + \frac{\mathrm{RP}(21) \cdot \mathrm{QMDBH}}{1000} - \frac{\mathrm{RP}(22) \cdot \mathrm{NT}}{1000}$$

Red Pine Objectives and Assumptions

1. Maintain red pine.
2. Manage for timber, particularly large products if possible.
3. Trees are uniformly distributed in the even-aged stands.
4. There is a low risk of loss from damaging agents.
5. Conditions are appropriate for using the clearcut silvicultural system.

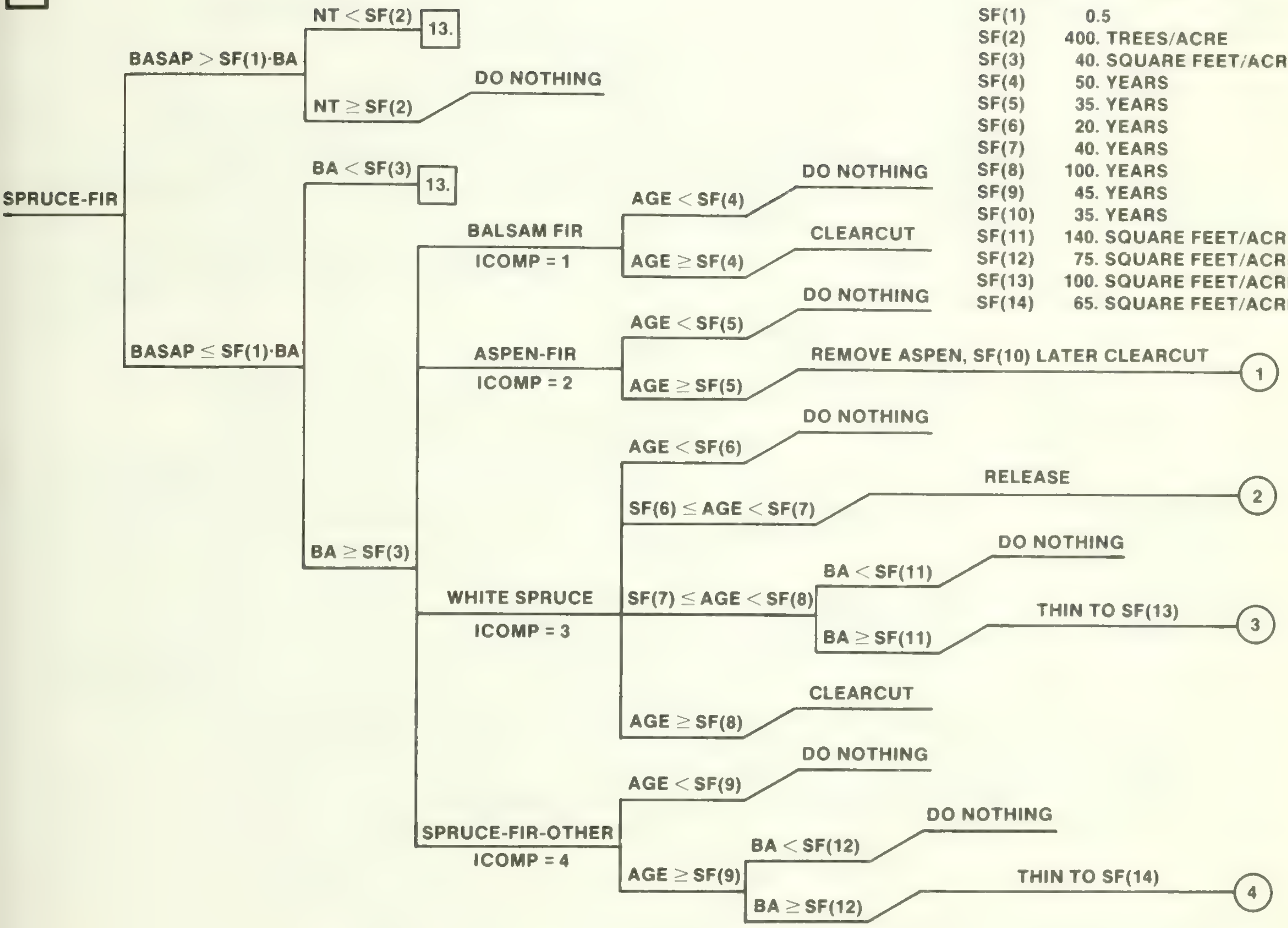


	CRITICAL VALUES
WP(1)	0.5
WP(2)	400. TREES/ACRE
WP(3)	20. YEARS
WP(4)	40. YEARS
WP(5)	120. YEARS
WP(6)	110. SQUARE FEET/ACRE
WP(7)	110. SQUARE FEET/ACRE
WP(8)	110. SQUARE FEET/ACRE
WP(9)	110. SQUARE FEET/ACRE
WP(10)	60. SQUARE FEET/ACRE
WP(11)	70. SQUARE FEET/ACRE
WP(12)	70. SQUARE FEET/ACRE
WP(13)	70. SQUARE FEET/ACRE
WP(14)	70. SQUARE FEET/ACRE
WP(15)	40. SQUARE FEET/ACRE

White Pine Objectives and Assumptions

1. Maintain white pine.
2. Manage for timber, particularly large products if possible.
3. Conditions are appropriate for using the shelterwood silvicultural system.
4. The stand is considered pure white pine if 80 percent of the basal area is in white pine. ICOMP = 1.
5. The stand is considered white-red pine if 70 percent of the basal area is in white and red pine. ICOMP = 2.
6. The stand is considered white pine-hardwood if 70 percent of the basal area is in white pine, basswood, sugar maple, white ash, and oak. ICOMP = 4.
7. The stand is considered white pine-spruce-fir if white spruce and balsam fir basal area is greater than hardwood or red pine basal area. ICOMP = 3.

4.



CRITICAL VALUES

SF(1)	0.5
SF(2)	400. TREES/ACRE
SF(3)	40. SQUARE FEET/ACRE
SF(4)	50. YEARS
SF(5)	35. YEARS
SF(6)	20. YEARS
SF(7)	40. YEARS
SF(8)	100. YEARS
SF(9)	45. YEARS
SF(10)	35. YEARS
SF(11)	140. SQUARE FEET/ACRE
SF(12)	75. SQUARE FEET/ACRE
SF(13)	100. SQUARE FEET/ACRE
SF(14)	65. SQUARE FEET/ACRE

Spruce-Fir Objectives and Assumptions

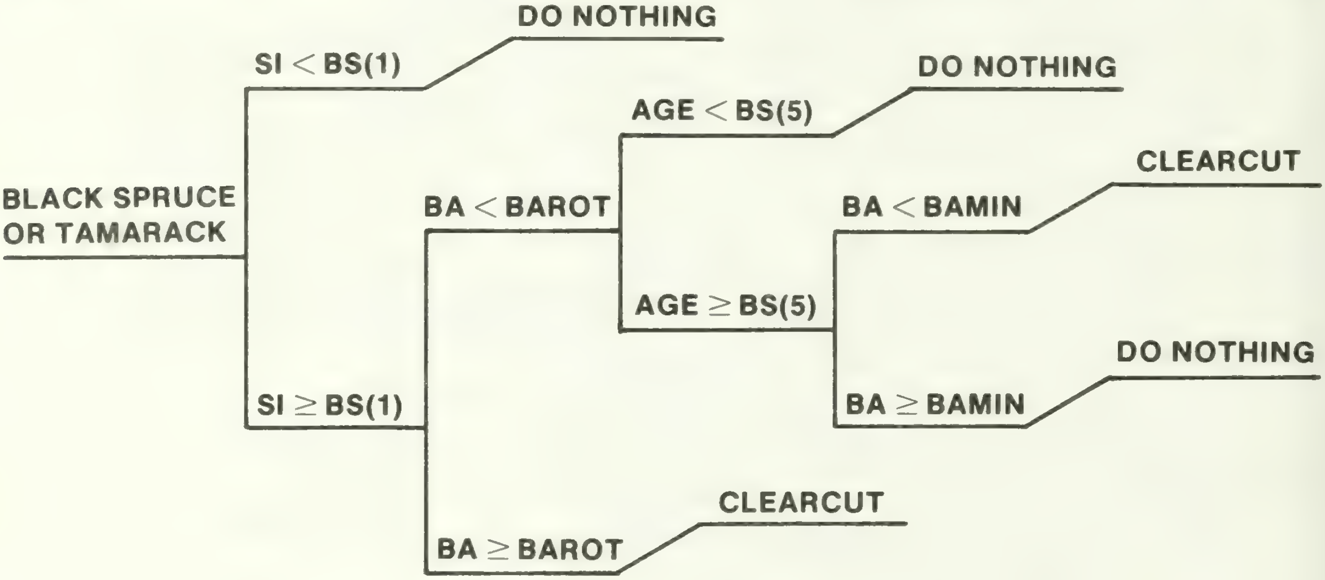
1. In stands which are predominantly balsam fir, manage for maximum fiber production and natural regeneration.
2. Manage white spruce for large products.
3. There is adequate advance regeneration of white spruce and balsam fir at the end of the rotation.
4. The stand is considered balsam fir if 80 percent of the basal area is in balsam fir. ICOMP = 1.
5. The stand is condsidered white spruce if 50 percent of the basal area is in white spruce. ICOMP = 3.
6. The stand is considered aspen-fir if 70 percent of the basal area is in aspen and balsam fir. ICOMP = 2.
7. Stands not meeting these criteria (4, 5, 6) are considered spruce-fir-other. ICOMP = 4.

5.

	CRITICAL VALUES
BS(1)	25. FEET
BS(2)	209. SQUARE FEET/ACRE
BS(3)	1837. SQUARE FEET/ACRE YEAR
BS(4)	10.6 SQUARE FEET/ACRE YEAR²
BS(5)	80. YEARS
BS(6)	-175.4 SQUARE FEET/ACRE
BS(7)	2.583 SQUARE FEET/ACRE YEAR

$$\text{BAROT} = \text{BS}(2) - \frac{\text{BS}(3) \cdot \text{AGE}}{1000} + \frac{\text{BS}(4) \cdot \text{AGE}^2}{1000}$$

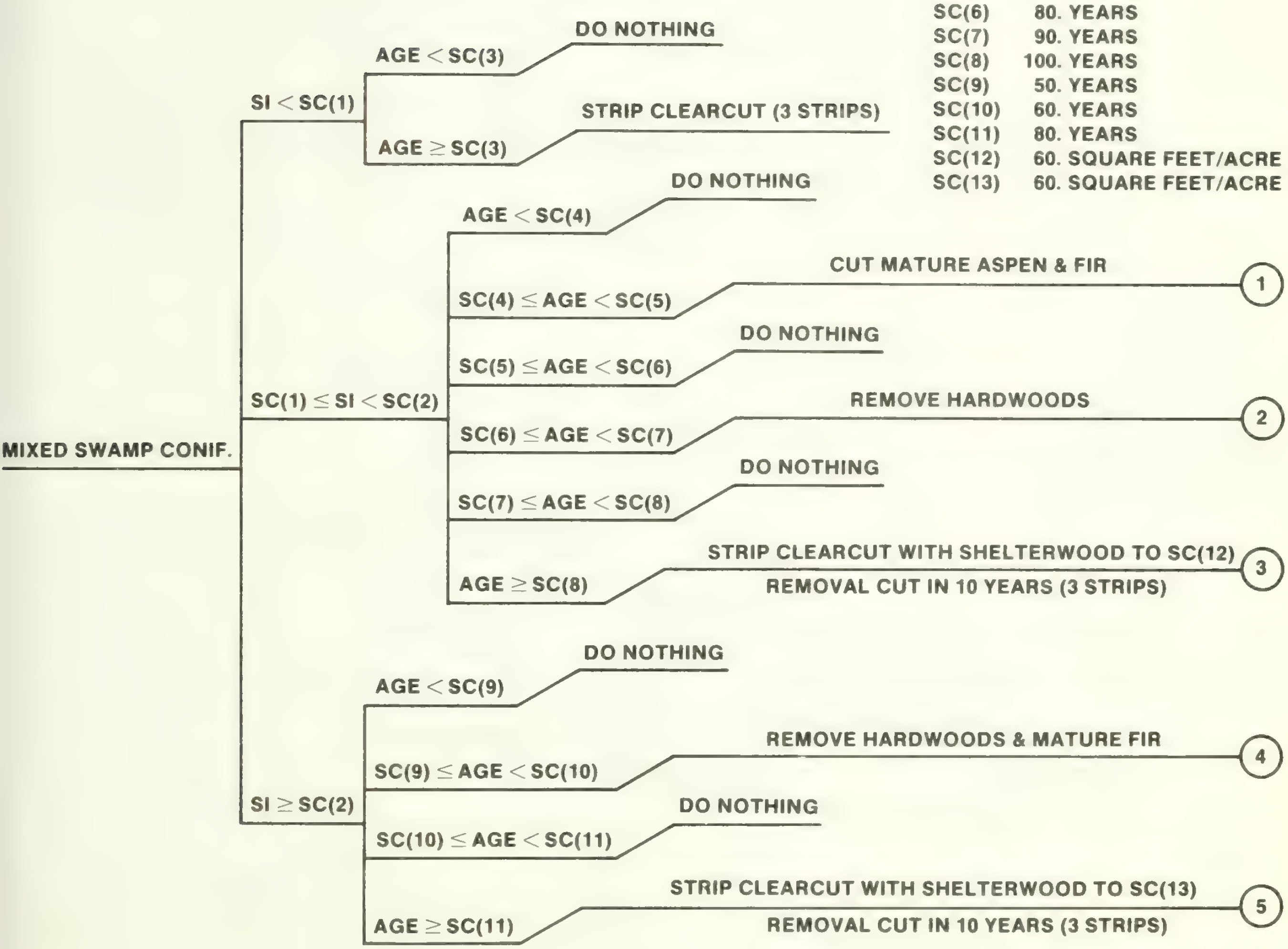
$$\text{BAMIN} = \text{BS}(6) + \text{BS}(7) \cdot \text{AGE}$$



Black Spruce (Tamarack) Objectives and Assumptions

1. Maintain black spruce.
2. Manage for pulpwood.
3. Stands occur on organic soil.
4. There is a low risk of loss from damaging agents.
5. Conditions are appropriate for using the clearcut silvicultural system.
6. Since very little is known about how to manage the tamarack type, black spruce management was selected as probably being the most reasonable regime to follow.

6.



CRITICAL VALUES

SC(1)	25. FEET
SC(2)	36. FEET
SC(3)	120. YEARS
SC(4)	50. YEARS
SC(5)	60. YEARS
SC(6)	80. YEARS
SC(7)	90. YEARS
SC(8)	100. YEARS
SC(9)	50. YEARS
SC(10)	60. YEARS
SC(11)	80. YEARS
SC(12)	60. SQUARE FEET/ACRE
SC(13)	60. SQUARE FEET/ACRE

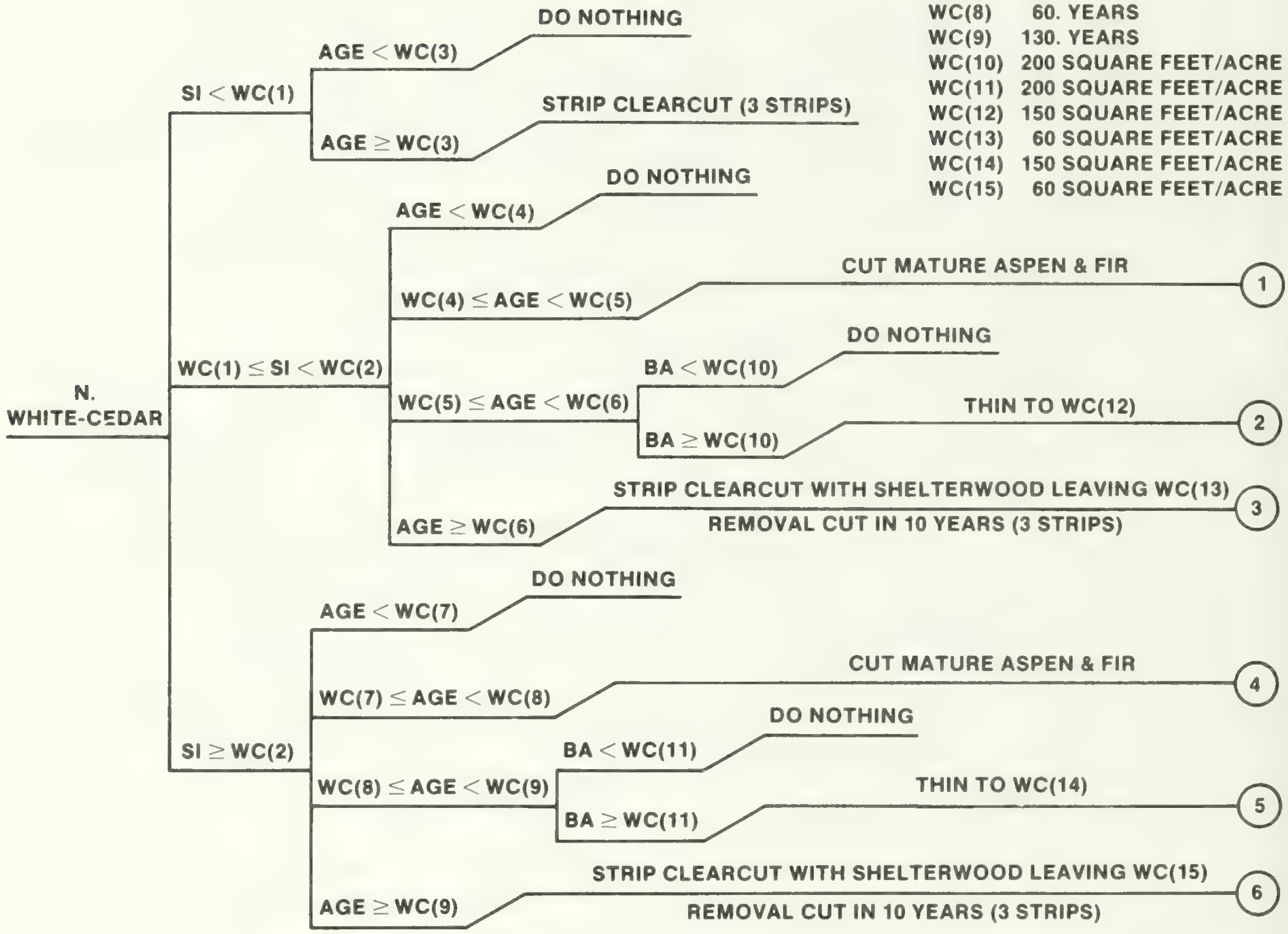
Mixed Swamp Conifer Objective and Assumptions

1. Maintain swamp conifers.
2. Manage for maximum fiber yield.
3. There is low risk of loss from damaging agents.
4. Conditions are appropriate for using the strip clearcut-shelterwood silvicultural system.

7.

CRITICAL VALUES

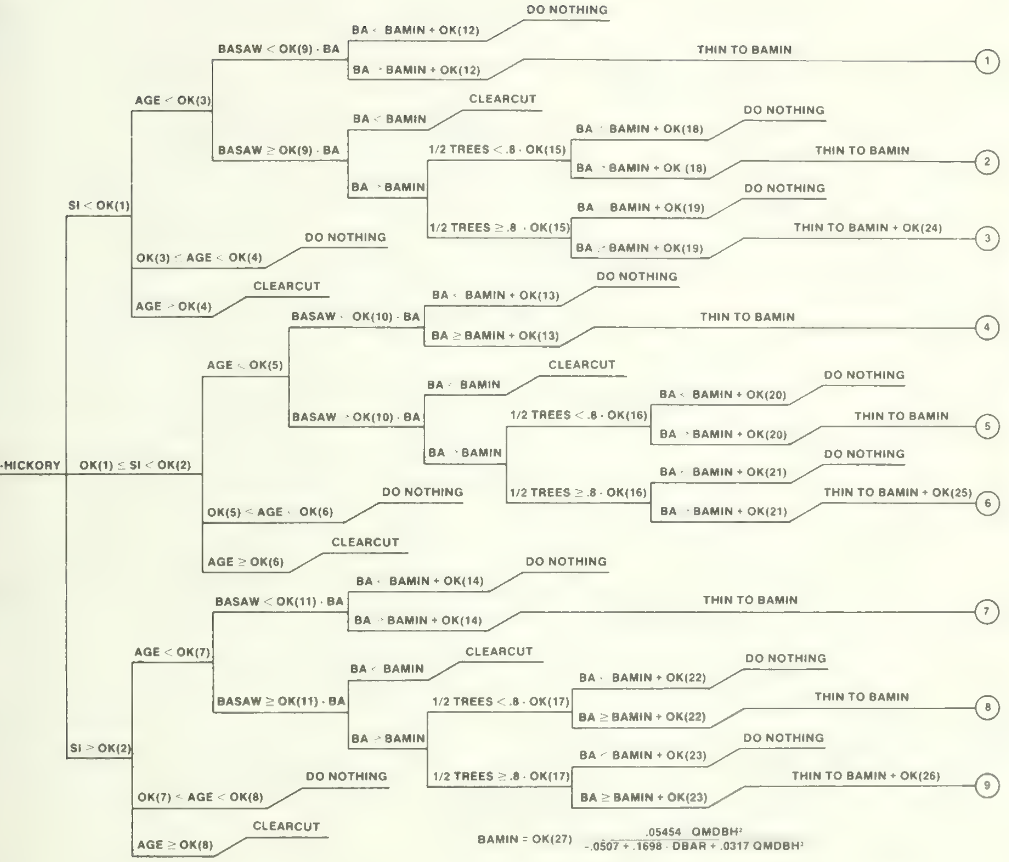
WC(1)	25. FEET
WC(2)	36. FEET
WC(3)	120. YEARS
WC(4)	50. YEARS
WC(5)	60. YEARS
WC(6)	150. YEARS
WC(7)	50. YEARS
WC(8)	60. YEARS
WC(9)	130. YEARS
WC(10)	200 SQUARE FEET/ACRE
WC(11)	200 SQUARE FEET/ACRE
WC(12)	150 SQUARE FEET/ACRE
WC(13)	60 SQUARE FEET/ACRE
WC(14)	150 SQUARE FEET/ACRE
WC(15)	60 SQUARE FEET/ACRE



Northern White-cedar Objectives and Assumptions

1. Maintain northern white-cedar.
2. Timber management and deeryard management are of equal importance.
3. Manage for large products since older stands also provide better shelter for deer.
4. Stand does not provide the only deer shelter in the area.
5. There is a low risk of loss from damaging agents.
6. Conditions are appropriate for using the strip clearcut-shelterwood silvicultural system.

8.



$$\text{BAMIN} = \text{OK}(27) \cdot \frac{.05454 \cdot \text{QMDBH}^2}{-.0507 + .1698 \cdot \text{DBAR} + .0317\ \text{QMDBH}^2}$$

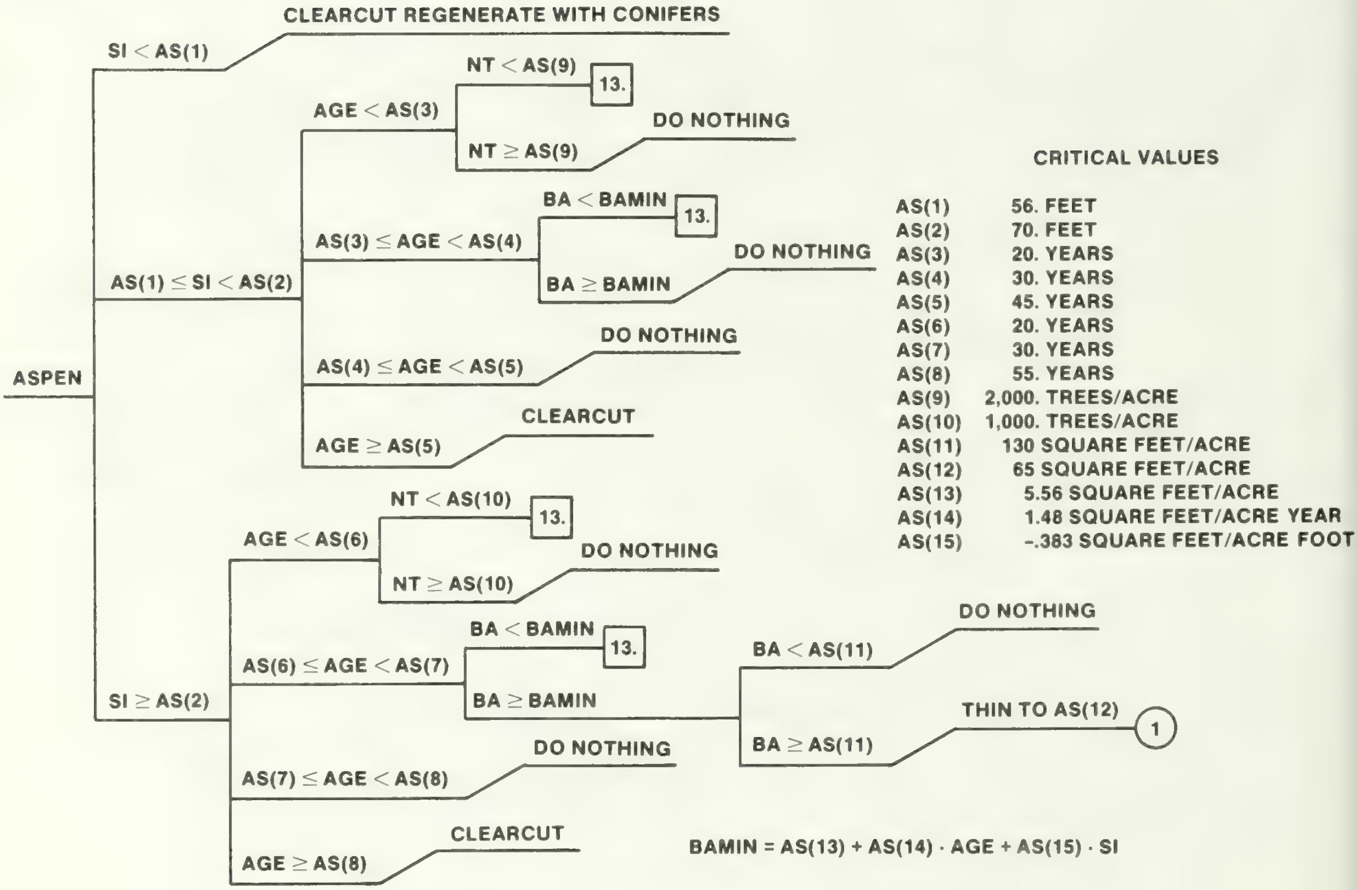
CRITICAL VALUES

OK(1)	55 FEET	
OK(2)	75 FEET	
OK(3)	60. YEARS	
OK(4)	100 YEARS	
OK(5)	60 YEARS	
OK(6)	80. YEARS	
OK(7)	50 YEARS	
OK(8)	70. YEARS	
OK(9)	0.5	
OK(10)	0 5	
OK(11)	0.5	
OK(12)	10. SQUARE FEET/ACRE	
OK(13)	10 SQUARE FEET/ACRE	
OK(14)	10. SQUARE FEET/ACRE	
OK(15)	16. INCHES	DESIRED ROTATION DIAMETER
OK(16)	20 INCHES	
OK(17)	24 INCHES	
OK(18)	10. SQUARE FEET/ACRE	
OK(19)	25. SQUARE FEET/ACRE	
OK(20)	10. SQUARE FEET/ACRE	
OK(21)	25. SQUARE FEET/ACRE	
OK(22)	10 SQUARE FEET/ACRE	
OK(23)	25. SQUARE FEET/ACRE	
OK(24)	15. SQUARE FEET/ACRE	
OK(25)	15. SQUARE FEET/ACRE	
OK(26)	15. SQUARE FEET/ACRE	
OK(27)	58. PERCENT STOCKED	

Oak-Hickory Objectives and Assumptions

1. Favor pines where the oak site index is low. Favor northern hardwoods where the oak site index is high. Otherwise, maintain oaks.
2. Manage for timber, particularly large products if possible.
3. The minimum acceptable stand basal area is dependent on the size of the trees present. That is, it is a measure of stocking. The percent of full stocking considered acceptable can be changed by altering the value of OK(27).
4. Advanced regeneration must be present before clearcutting.

9.



CRITICAL VALUES

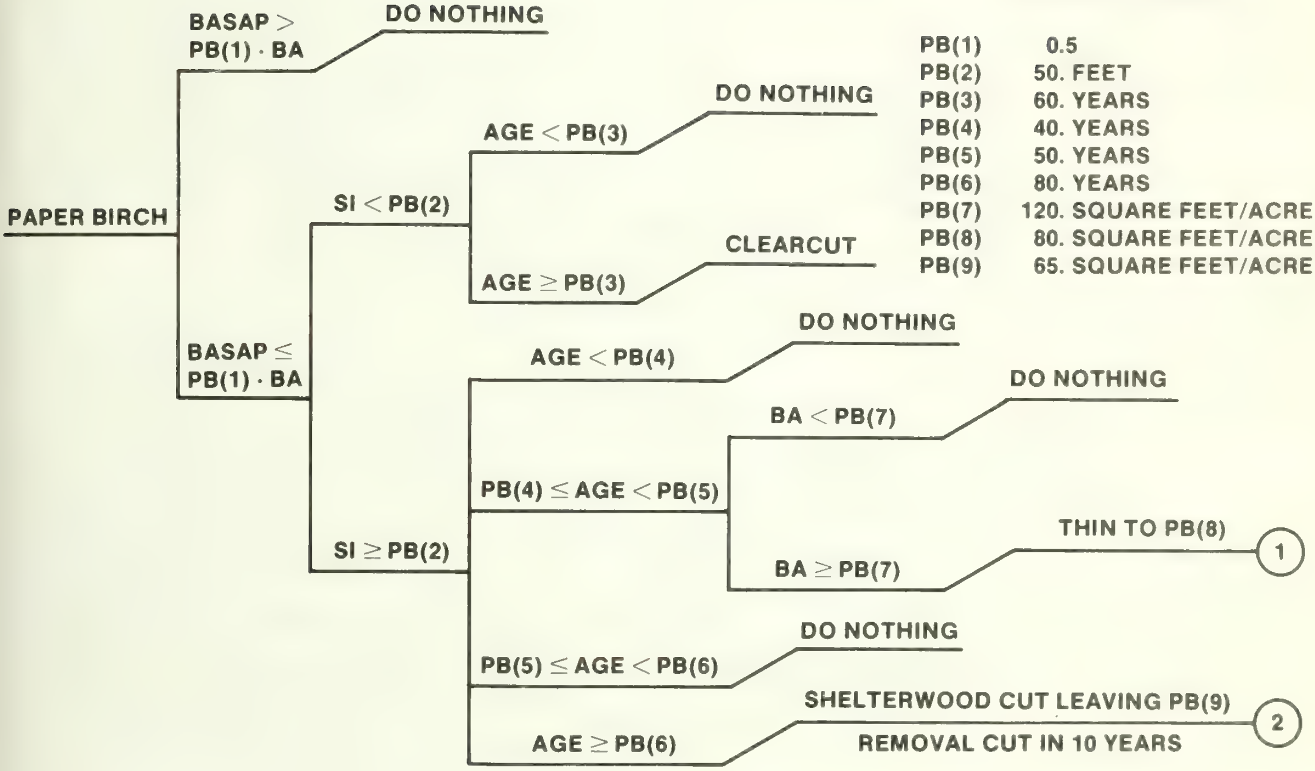
AS(1)	56. FEET
AS(2)	70. FEET
AS(3)	20. YEARS
AS(4)	30. YEARS
AS(5)	45. YEARS
AS(6)	20. YEARS
AS(7)	30. YEARS
AS(8)	55. YEARS
AS(9)	2,000. TREES/ACRE
AS(10)	1,000. TREES/ACRE
AS(11)	130 SQUARE FEET/ACRE
AS(12)	65 SQUARE FEET/ACRE
AS(13)	5.56 SQUARE FEET/ACRE
AS(14)	1.48 SQUARE FEET/ACRE YEAR
AS(15)	-.383 SQUARE FEET/ACRE FOOT

$BAMIN = AS(13) + AS(14) \cdot AGE + AS(15) \cdot SI$

Aspen Objectives and Assumptions

1. Maintain aspen on better sites.
2. Manage for timber, particularly large products if possible.
3. Understocked stands are not capable of producing 1,000 cubic feet per acre at age 40.

10.

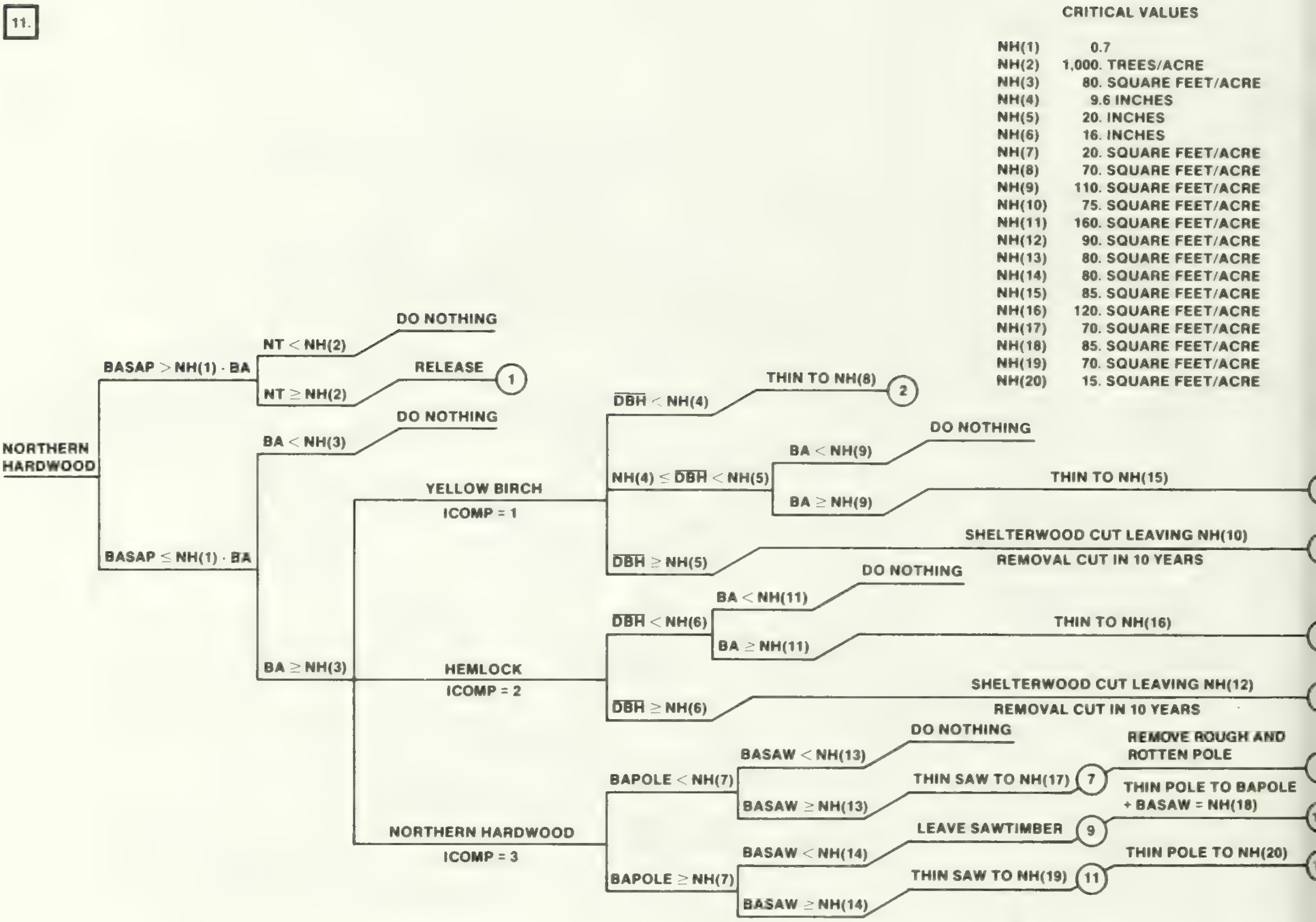


	CRITICAL VALUES
PB(1)	0.5
PB(2)	50. FEET
PB(3)	60. YEARS
PB(4)	40. YEARS
PB(5)	50. YEARS
PB(6)	80. YEARS
PB(7)	120. SQUARE FEET/ACRE
PB(8)	80. SQUARE FEET/ACRE
PB(9)	65. SQUARE FEET/ACRE

Paper Birch Objectives and Assumptions

1. Maintain paper birch on better sites, convert to conifers on other sites.
2. Manage for timber, particularly large products if possible.
3. Conditions are appropriate for using the shelterwood silvicultural system on better sites. The assumption is made that the removal cut will also include scarification.

11.



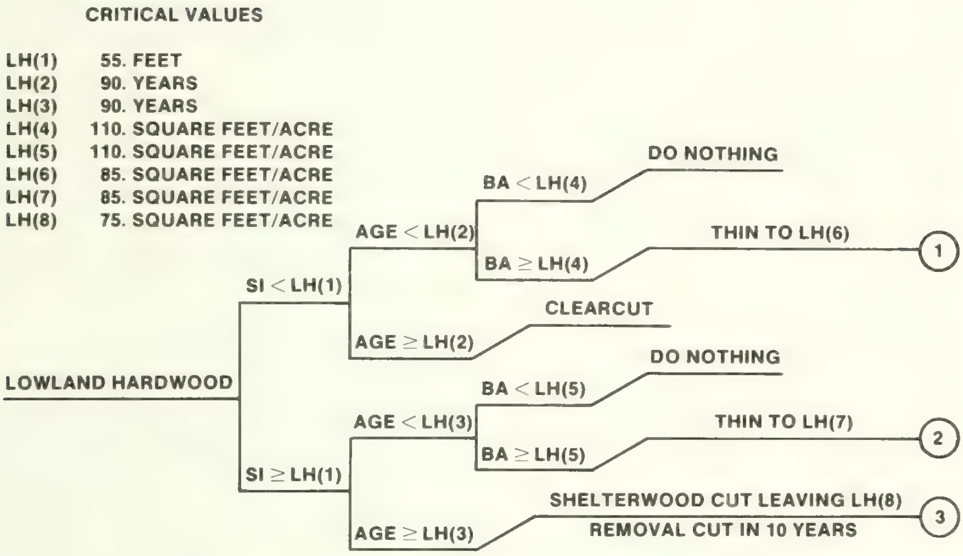
CRITICAL VALUES

NH(1)	0.7
NH(2)	1,000. TREES/ACRE
NH(3)	80. SQUARE FEET/ACRE
NH(4)	9.6 INCHES
NH(5)	20. INCHES
NH(6)	16. INCHES
NH(7)	20. SQUARE FEET/ACRE
NH(8)	70. SQUARE FEET/ACRE
NH(9)	110. SQUARE FEET/ACRE
NH(10)	75. SQUARE FEET/ACRE
NH(11)	160. SQUARE FEET/ACRE
NH(12)	90. SQUARE FEET/ACRE
NH(13)	80. SQUARE FEET/ACRE
NH(14)	80. SQUARE FEET/ACRE
NH(15)	85. SQUARE FEET/ACRE
NH(16)	120. SQUARE FEET/ACRE
NH(17)	70. SQUARE FEET/ACRE
NH(18)	85. SQUARE FEET/ACRE
NH(19)	70. SQUARE FEET/ACRE
NH(20)	15. SQUARE FEET/ACRE

Northern Hardwood Objectives and Assumptions

1. Maintain or develop all-aged northern hardwood stands.
2. Manage for timber, particularly large products if possible.
3. Maintain stands that are primarily yellow birch or hemlock through the use of the shelterwood silvicultural system.
4. If yellow birch basal area is more than 25 percent of the northern hardwood basal area the stand is considered primarily yellow birch. ICOMP = 1.
5. If hemlock basal area is more than 50 percent of the northern hardwood basal area the stand is considered primarily hemlock. ICOMP = 2.
6. If conditions 4 or 5 are not met the stand is considered northern hardwoods. ICOMP = 3.

12.



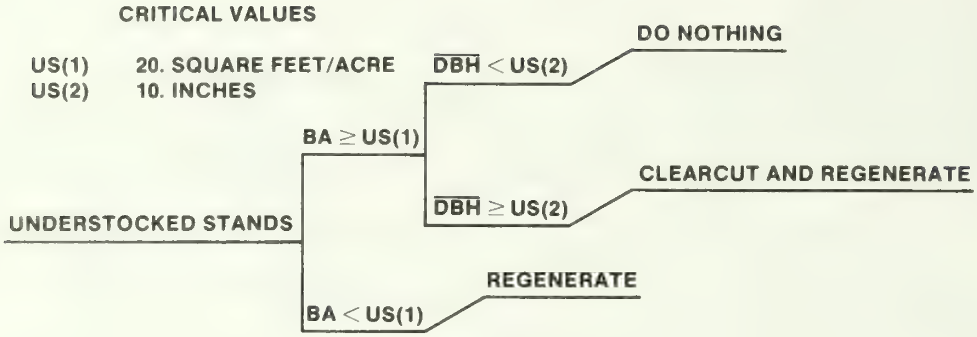
CRITICAL VALUES

LH(1)	55. FEET
LH(2)	90. YEARS
LH(3)	90. YEARS
LH(4)	110. SQUARE FEET/ACRE
LH(5)	110. SQUARE FEET/ACRE
LH(6)	85. SQUARE FEET/ACRE
LH(7)	85. SQUARE FEET/ACRE
LH(8)	75. SQUARE FEET/ACRE

Lowland Hardwood Objectives and Assumptions

1. Manage for timber.
2. Advanced regeneration must be present before the overstory is removed. Very little is known about how to manage lowland hardwoods.

13.



Understocked Stand Objectives and Assumptions

1. Stands with a basal area less than 20 square feet are open enough so that they can be regenerated without removing the overstory.
2. Stands with a basal area greater than 20 square feet will be operable if the average diameter is greater than 10 inches.

APPENDIX B

Marking rules in this section are preceded by a number that designates the final position in the management diagrams. These numbers appear within circles in the management diagrams. Removal procedures follow a verbal description of the marking rule.

Jack Pine

1. Remove overtopping trees.
   Procedure: 1. Remove trees over 10 inches d.b.h.
2. Remove overtopping trees and leave 1,000 trees/acre.
   Procedure: 1. Remove trees over 10 inches d.b.h.
   2. Remove trees until there are only 1,000 trees/acre.
3. Remove rough and rotten trees and thin from below favoring pines and white spruce until BA is less than the larger of JP(10) or JP(11) × BA.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine, white spruce.
   3. Remove small d.b.h., jack pine, red pine, white pine, white spruce.

Red Pine

1. Remove undesirable species (red pine, jack pine, white pine, and white spruce are desirable) and overtopping trees.
   Procedure: 1. Remove non-red pine, jack pine, white pine, white spruce.
   2. Remove trees over 12 inches d.b.h.
2. Remove undesirable species and overtopping trees and reduce the number of trees to 1,000 trees/acre.
   Procedure: 1. Remove non-red pine, jack pine, white pine, white spruce.
   2. Remove trees over 12 inches d.b.h.
   3. Remove trees until there are only 1,000 trees/acre.
3. Reduce the number of trees to 1,000 trees/acre.
   Procedure: 1. Remove trees until there are only 1,000 trees/acre.
4. Remove rough and rotten trees and thin from below favoring red pine until BA is less than the larger of RP(15) or RP(16) × BA.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-red pine.
   3. Remove small d.b.h., red pine.
5. Remove rough and rotten trees and thin from below favoring red pine until BA is less than the larger of RP(17) or RP(18) × BA.
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-red pine.
   3. Remove small d.b.h., red pine.
6. Remove rough and rotten trees and thin from below favoring red pine until BA is less than RP(19).
   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-red pine.
   3. Remove small d.b.h., red pine.

White Pine

1. Remove overtopping trees and undesirable species (white pine, red pine, and white spruce are desirable).
   Procedure: 1. Remove non-white pine, red pine, white spruce.
   2. Remove trees over 12 inches d.b.h.
2. Remove mature aspen and jack pine, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(11).
   Procedure: 1. Remove jack pine and aspen over 6 inches d.b.h.
   2. Remove rough and rotten trees.
   3. Remove small d.b.h., non-white pine, red pine, white spruce.
   4. Remove small d.b.h., white pine, red pine, white spruce.
3. Remove mature aspen and jack pine, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(12).
   Procedure: 1. Remove jack pine and aspen over 6 inches d.b.h.

    2. Remove rough and rotten trees.
    3. Remove small d.b.h., non-white pine, red pine, white spruce.
    4. Remove small d.b.h., white pine, red pine, white spruce.

4. Remove mature balsam fir, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(13).
   Procedure:
    1. Remove balsam fir over 5 inches d.b.h.
    2. Remove rough and rotten trees.
    3. Remove small d.b.h., non-white pine, red pine, white spruce.
    4. Remove small d.b.h., white pine, red pine, white spruce.
5. Remove mature aspen and jack pine, rough and rotten trees, and thin from below favoring white and red pine and white spruce until BA is less than BAMIN + WP(14).
   Procedure:
    1. Remove jack pine and aspen over 6 inches d.b.h.
    2. Remove rough and rotten trees.
    3. Remove small d.b.h., non-white pine, red pine, white spruce.
    4. Remove small d.b.h., white pine, red pine, white spruce.
6. Make a shelterwood cut leaving WP(10) square feet/acre in seed cutting (favor white pine) with a removal cut 10 years later.
   Procedure:
    1. Remove rough and rotten trees.
    2. Leave largest d.b.h., highest crown ratio white pine.

Spruce-fir

1. Remove aspen and leave the balsam fir to grow for another SF(10) years, then clearcut.
   Procedure:
    1. Remove aspen.
    2. SF(10) years later clearcut (should contain another stand of aspen).
2. Remove overtopping trees and non-white spruce.
   Procedure:
    1. Remove non-white spruce.
    2. Remove trees over 12 inches d.b.h.
3. Remove rough and rotten trees and thin favoring white spruce until BA is less than SF(13). Thin from above in non-white spruce and from below in white spruce.
   Procedure:
    1. Remove rough and rotten trees.
    2. Remove large d.b.h., non-white spruce.
    3. Remove small d.b.h., white spruce.
4. Remove rough and rotten trees and thin favoring white spruce until BA is less than SF(14). Thin from above in non-white spruce and from below in white spruce.
   Procedure:
    1. Remove rough and rotten trees.
    2. Remove large d.b.h., non-white spruce.
    3. Remove small d.b.h., white spruce.

Mixed Swamp Conifer

1. Remove mature aspen and balsam fir.
   Procedure:
    1. Remove aspen over 6 inches d.b.h.
    2. Remove balsam fir over 5 inches d.b.h.
2. Remove hardwoods.
   Procedure:
    1. Remove elm, aspen, paper birch.
    2. Remove black ash, red maple, yellow birch.
3. Make a shelterwood cut leaving SC(12) square feet/acre in seed cutting (favor northern white-cedar, black spruce, white spruce, and tamarack) with a removal cut 10 years later. (Done for the third strip only.)
   Procedure:
    1. Remove rough and rotten trees.
    2. Leave largest d.b.h., highest crown ratio northern white-cedar, black spruce, white spruce, tamarack.
4. Remove hardwoods and mature balsam fir.
   Procedure:
    1. Remove balsam fir over 5 inches d.b.h.
    2. Remove elm, aspen, paper birch.
    3. Remove black ash, red maple, yellow birch.
5. Make a shelterwood cut leaving SC(13) square feet/acre in seed cutting (favor northern white-cedar, black spruce, white spruce, and tamarack) with a removal cut 10 years later. (Done for the third strip only.)
   Procedure:
    1. Remove rough and rotten trees.
    2. Leave largest d.b.h., highest crown ratio northern white-cedar, black spruce, white spruce, tamarack.

Northern White-cedar

1. Remove mature aspen and balsam fir.
   Procedure:
    1. Remove aspen larger than 6 inches d.b.h.

   2. Remove balsam fir larger than 5 inches d.b.h.

2. Remove rough and rotten trees and thin from below favoring white spruce, black spruce, and northern white-cedar until BA is less than WC(12).

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-white spruce, black spruce, northern white-cedar.
   3. Remove small d.b.h., white spruce, black spruce, northern white-cedar.

3. Make a shelterwood cut leaving WC(13) square feet/acre in seed cutting (favor white spruce, black spruce, and northern white-cedar) with a removal cut 10 years later. (Done for the third strip only.)

   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio white spruce, black spruce, northern white-cedar.

4. Remove mature aspen and balsam fir.

   Procedure: 1. Remove aspen larger than 6 inches d.b.h.
   2. Remove balsam fir larger than 5 inches d.b.h.

5. Remove rough and rotten trees and thin from below favoring white spruce, black spruce, and northern white-cedar until BA is less than WC(14).

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-white spruce, black spruce, northern white-cedar.
   3. Remove small d.b.h., white spruce, black spruce, northern white-cedar.

6. Make a shelterwood cut leaving WC(15) square feet/acre in seed cutting (favor white spruce, black spruce, and northern white-cedar) with a removal cut 10 years later. (Done for the third strip only.)

   Procedure: 1. Remove rough and rotten trees.
   2. Leave largest d.b.h., highest crown ratio white spruce, black spruce, northern white-cedar.

Oak-hickory

1. Remove rough and rotten trees and thin from below favoring pines until BA is less than BAMIN.

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine.
   3. Remove small d.b.h., jack pine, red pine, white pine.

2. Remove rough and rotten trees and thin from below favoring pines until BA is less than BAMIN.

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine.
   3. Remove small d.b.h., jack pine, red pine, white pine.

3. Remove rough and rotten trees and thin from below favoring pines until BA is less than BAMIN + OK(24).

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-jack pine, red pine, white pine.
   3. Remove small d.b.h., jack pine, red pine, white pine.

4. Remove rough and rotten trees and thin from below favoring oaks and hickories until BA is less than BAMIN.

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-oaks and hickories.
   3. Remove small d.b.h., oaks and hickories.

5. Remove rough and rotten trees and thin from below favoring oaks and hickories until BA is less than BAMIN.

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-oaks and hickories.
   3. Remove small d.b.h., oaks and hickories.

6. Remove rough and rotten trees and thin from below favoring oaks and hickories until BA is less than BAMIN + OK(25).

   Procedure: 1. Remove rough and rotten trees.
   2. Remove small d.b.h., non-oaks and hickories.
   3. Remove small d.b.h., oaks and hickories.

7. Remove rough and rotten trees and thin from below favoring sugar maple, basswood, and white ash until BA is less than BAMIN.

   Procedure: 1. Remove rough and rotten trees.

Brand, Gary J.

1981. Simulating timber management in Lake States forests. U.S. Department of Agriculture Forest Service, General Technical Report NC-69, 25 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Describes in detail a management subsystem to simulate cutting in Lake States forest types. This subsystem is part of a Stand and Tree Evaluation and Modeling System (STEMS) contained in the Forest Resource Evaluation Program (FREP) for the Lake States. The management subsystem can be used to test the effect of alternate management strategies.

KEY WORDS: silviculture guide, computer model, growth model.

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The User's Guide To STEMS

Stand and Tree Evaluation and Modeling System

David M. Belcher

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THE USER'S GUIDE TO STEMS (STAND AND TREE EVALUATION AND MODELING SYSTEM)

David M. Belcher, *Research Forester*

STEMS is a system of computer programs that projects the growth of individual trees in stands. It was developed at the North Central Forest Experiment Station as part of the Forest Resources Evaluation Program (FREP). Based on biological principles of forest growth, STEMS offers a flexible, generalized approach to simulating the change of forest trees in stands. Coefficients for its generalized diameter growth and mortality functions have been developed from more than 2,500 permanent remeasured plots for all the major tree species in the Lake States—Minnesota, Wisconsin, and Michigan. STEMS is an individual tree, distance independent model that can provide much detail about trees and stands. Because each tree is projected individually, the system offers users the opportunity to tailor output and silvicultural treatment subroutines to meet their specific objectives. User control of management options and types of summaries further serves to make STEMS suitable to a variety of user needs. Changes for a single stand may be monitored in great detail and whole forest inventories may be projected. Information about FREP and earlier versions of the tree growth projection system have been previously published by Buchman (1978), Lundgren (1978), Lundgren and Essex (1978), USDA Forest Service (1979), Hahn *et al.* (1979), and Smith and Raile (1979).

This User's Guide does not require an extensive knowledge of programming. However, a basic familiarity with some of the terminology used in data processing will be beneficial. First the organization of the STEMS system is presented. Then the required input, the processing that is done, and the output that is produced are discussed in detail for each part of the system.

SYSTEM ORGANIZATION

STEMS consists of two separate programs—TGPS and TABL (fig. 1). The TGPS (Tree Growth Processor) program is the main part of STEMS. TGPS "grows" stands of forest trees by estimating the growth of individual trees with a series of projection equations. These projection equations predict annual diameter growth of the tree, probability of mortality, and crown ratio. Stand characteristics may be computed from the updated individual tree characteristics. A Standard Output File of initial and updated tree lists is produced for later summarization by TABL or other programs.

The TABL program is provided to summarize the Standard Output File by species group and user-specified diameter classes. Summaries are produced for each plot and for all plots at the end of each growth or management cycle and at the end of the projection. Details of the tables are presented under the OUTPUT heading in the TABL section of this paper.

STEMS does not contain a standard read routine for the initial tree lists because it is unlikely that any two users will have their data in the same form. Therefore the user must write his own read routine. A sample read routine with an associated initial tree list is presented in Appendix I.

TGPS: THE TREE GROWTH PROCESSOR

Input

Input to TGPS consists of four separate parts: run options, optional volume coefficients, system parameters and specifications, and initial tree lists to be projected. Individual subroutines are available for input of each part.

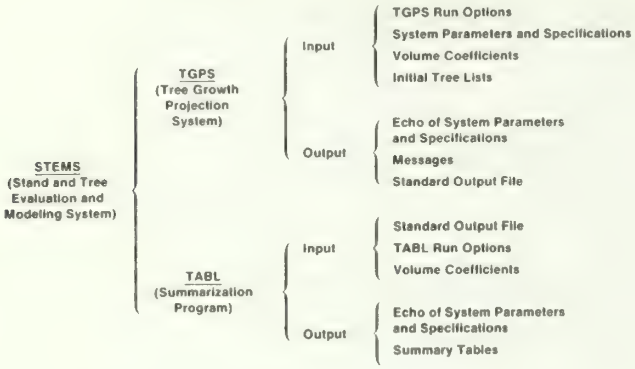

Figure 1.—*Organization of STEMS.*

Run options

Run options determine the characteristics of the projection by setting values such as the length of the projection, management option to be applied, and types of output to be produced from TGPS. Subroutine SETRUN is used to enter this information. To make this input as simple as possible, a keyword type process is employed. Each available option has a keyword and associated value. The keywords can appear in any order within the run option file. Each keyword has a default value so that only a minimum number of entries is required. These options will be modified frequently as the user chooses different ways to run STEMS.

The keywords must be in the first four columns of each record and columns 5-19 may be used to expand the keyword into a more readable form. Each keyword that requires a value must have that value in columns 20-29 and must have a decimal point included.

These are the options used to produce the example presented later in this guide.

```
TITLE
"STEMS": SAMPLE RUN FOR RELEASE VERSION OF THE TREE GROWTH PROJECTION SYSTEM.
CYCLES               3.   NUMBER OF GROWTH CYCLES.
YEARS IN CYCLE      10.   YEARS *CYCLES = 30 YEAR PROJECTION.
PLOTS TO PROCESS     0.   NUMBER OF PLOTS. 0 MEANS ALL PLOTS WILL BE USED.
MORTALITY            1.   0=DETERMINISTIC, 1=PROBABILISTIC.
MANAGEMENT           2.   2=MID-POINT OF EACH CYCLE.
REGENERATION         1.   1=USED AS NEEDED, 0=NOT USED.
UNITS FOR VOLUME     0.   0=NO VOLUMES, 1=BIOMASS, 2=CU.FT., 3=BD.FT, ...
STANDARD OUTPUT      1.   1=WRITTEN AS CODED FILE,3=BINARY.
FREQUENCY OF OUTPUT  1.   1=TREE LISTS WRITTEN BY CYCLE, 0=YEARLY.
USER OUTPUT          0.   0=NONE, 4=BY CYCLE.
MESSAGES             4.   INFORMATIVE MESSAGE CODE.
ECHO OF PARAMETERS   1.   1 MEANS SYSTEM PARAMETERS WILL BE PRINTED.
DEBUG                0.   DEBUG SUBROUTINE WILL NOT BE USED.
SEED                31.   RANDOM NUMBER SEED.
```

The following keywords are available in TGPS:

KEYBOARD	DEFINITION	DEFAULT
TITL	User specified run title should appear on the record following this keyword and should be typed within the first 80 columns.	All blanks
RUN	Run identification should appear on the record following this keyword and should be typed within the first 16 columns. Used only when standard output summaries will be used.	All blanks
TYPE	Run type: 1 = validation; 2 = projection. (Validation is not discussed in this Guide)	2.
CYCL	Number of growth or management cycles.	0.
YEAR	Number of years in each cycle.	0.
PLOT	Number of plots to be processed. 0 = process all plots on the TAPE11 input file.	1.
MANA	Management: 0 = no management; 1 = management routines called on first year of each cycle; 2 = mid-point management; 3 = last year management; 4 = user will specify management years with keyword CUT.	0.
CUT	User specified years for calling management routines should appear on the record following this keyword and should start in column 1 with one space between each year. Maximum number of years is 10 and decimal points must not be used. This keyword must be specified if MANA = 4.	All zero's
REGE	Regeneration: 0 = regeneration routines will not be used; 1 = regeneration routines will be called as needed.	0.
MORT	0 = deterministic; 1 = probabilistic.	1.
UNIT	0 = no volumes of any kind will be computed; 1 = biomass in cubic feet; 2 = cubic feet; 3 = board feet; 4 = cubic feet in saw logs; 5 = cords (79 cubic feet/cord).	0.
MESS	Informative messages: 0 = No messages; 1 = TESTIT block only; 2 = TESTIT and short tree list information; 3 = TESTIT and short management summary; 4 = 2 + 3; 5 = 4 + notes at entry and exit of major subroutines; 6 = 5 + extra notes.	0.

STAN	Standard output: 0 = no Standard Output File will be produced; 1 = both the projected tree lists and system parameter files will be written in coded format; 2 = tree lists (coded), no parameter file; 3 = tree lists (binary), parameter file (coded); 4 = tree lists (binary), no parameter file. Note that use of program TABL requires a parameter file to be produced by TGPS.	1.
FREQ	Frequency of standard output: 0 = tree lists written to Standard Output File yearly; 1 = tree lists written at end of each cycle.	1.
USER	User output: Selects time of call to user written Subroutine OUTUR. 0 = no calls will be made to Subroutine OUTUR; 1 = OUTUR called before any projection is done; 2 = OUTUR called for each plot after the initial tree list is read but before the plot begins projection. Initial conditions will be printed at this point; 3 = OUTUR called at the end of each year of projection for each plot; (**Caution:** this may produce a lot of output). 4 = OUTUR called at the end of each cycle for a plot; 5 = OUTUR called at the end of all cycles for a plot; 7 = OUTUR called at the end of all cycles for all plots. (Final summary).	0.
ECHO	Echo check: 1 = list of system parameters and equation coefficients; 0 = no list.	0.
DEBU	Selects time of call to diagnostic Subroutine DEBUG. The codes are the same as for Subroutine OUTUR.	0.
READ	Read routine: 1 = SILV-EXAM read routine; 2 = User's Guide example; 3 = National Forest; 4 = User's own routine.	31.
WAIT	Minimum number of years to wait between thinning and clearcut for all management guides.	0.

Volume and biomass coefficients

Tree volumes are not a formal part of the TGPS program. However, users who wish to do their own output through use of Subroutine OUTUR may also wish to have the capability to compute volumes. Coefficients for the standard volume equations included in TGPS are entered with Subroutine SETVOL.

Volume and biomass equations provided in STEMS produce estimates of tree volume in a variety of units. One unit is chosen for all volume computations for a run with the keyword UNIT. Note that UNIT can be specified as 0 for runs in which no volume computations are desired. Volume information can be developed for each of the available units through repeated runs of the programs.

This version of STEMS contains two sets of volume equations—one was developed for northeastern Minnesota (Raile 1980) and the other was developed for Wisconsin (Hahn 1973). The user chooses an equation by using the appropriate volume coefficient file. Each file has a State code identifier that indicates the correct equation form to be used. The equations were provided by the North Central Forest Experiment Station Renewable Resources Evaluation Project.[1]

---

[1] *Personal communication with W. B. Smith and Gerhard Raile of North Central Forest Experiment Station, October 1979.*

Appendix II contains a list of the volume and biomass coefficients supplied with STEMS. See the Programmer's Guide (In preparation) for details on replacing these volume equations with your own.

System parameters and specifications

The System Parameter file contains the coefficients for the projection equations, species group assignments, critical values for management guides and regeneration, and other values necessary for operating TGPS. Subroutine SETSYS is used to read these values. This file is read before projection of the first plot begins. Appendix III contains a complete list of the system parameters and specifications.

The first section of this file sets the conversions from user species codes to FREP species groups. The species codes used are the standard codes given in the USDA Forest Service Handbook. These codes appear in the first column of numbers. The second column holds the FREP species group number to which the user species will be assigned. The next column holds names of the user species and is not used by STEMS but may be used for descriptive purposes within the file. The last column holds up to 12 letters for the name of the FREP species group. For example: species number 746 is assigned to FREP species group 25 and given the name QUAK.ASPEN (quaking aspen). Species with similar characteristics or insufficient data may be combined within a group. For example, all the elms are combined into species group 15 and assigned the name ELM. Users who wish to alter the species group assignments should do so carefully because the projection equation coefficients are all calibrated by species group, not by species.

The second section of the system parameter file contains the crown ratio function coefficients followed by a section holding the cover type names and management guide assignments. The first column of numbers is the cover type code and is referred to as KTYPE. The second column is the code for the management guide that will be associated with this cover type. For a thorough discussion see Brand (1979, 1981).

Critical values for the management guides are presented next. Alternative management strategies can be examined by altering these critical values. Each guide has a variety of values, each with its own meaning. These values are also discussed in Brand (1979, 1981).

The following two sections in the system parameter file hold coefficients for the mortality and potential growth equations. The first line in each section assigns equations to species groups with the first number in the assignment line being the number of equations available. Each of the subsequent positions in this line holds the equation number assigned to the species group in the corresponding position. For example, equation 2 in the mortality section (red pine) is assigned to species group 10 (other softwoods) because the number 2 appears in the 10th position in the assignment line. A discussion of the mortality and potential functions is presented in USDA Forest Service (1979).

The modifier function coefficients appear next.[2] Changes in these coefficients, as for the mortality and potential coefficients, require refitting the models and should not be done without a thorough statistical examination. However, the coefficient in the second column in exponential notation is an exception. It is maximum basal area expected for a species group and can be changed by approximately 50 square feet to more closely approximate the user's situation without refitting the model.

The next section presents decision values for the marking rules used in the management guides. The values set cutting diameter limits, order of cut by tree species and tree class, etc. See Brand (1979, 1981) for a discussion of the marking rules and suggestions for modification of these values.

Species site index conversion coefficients are presented next (Carmean and Vasilevsky 1971, and Carmean 1979). Each entry consists of four items: the predictor species group number, the predicted species group number, and the intercept and slope coefficients for the simple linear regression. For example, if plot site index is measured on jack pine (species group 1), site index for red pine (species group 2) on that plot is computed as SIrp = 19.38 + 0.64 (SIjp).

Critical values for regeneration consist of one or more lines for each "block". A block is a description of the new stand that occurs at the end of a branch in the regeneration decision trees (see the regeneration section of this Guide for a discussion of the decision trees). The information presented for a block is:

Column	**Description**
1-2	Cover type identification.
3-4	Management guide used to remove previous stand.
5-6	Block number within management guide.

---

[2] *The modifer function and coefficients used here were developed by M. R. Holdaway, North Central Forest Experiment Station.*

8	Type of origin for new stand: 1 = natural; 2 = plant.
10	Site preparation code: 0 = site preparation assumed not done; 1= assumed done.
12	Release code: 0 = assumed not done; 1 = assumed done.
13-14	Number of species groups on new plot.
15-17	Species group number for new trees
18-22	Number of trees/acre for this species group.
23-26	Arithmetic average diameter for this species group.
27-31	Standard deviation about the average diameter.

Species group number, number of trees/acre, average diameter, and standard deviation are repeated for each species group present in the new stand using the same format as used in columns 15-31.

The final section holds coefficients for computing individual tree height. The height equations are currently being developed by Dr. Alan R. Ek of the University of Minnesota, College of Forestry. Until the development of these equations is complete, space is reserved for the coefficients and is filled with zeros.

Initial tree lists

Initial tree lists for projection must be prepared by the user and read by the user-written Subroutine READ. Each tree list represents a stand of trees that may be actual measurements or hypothetical data. The tree list file can consist of any number of tree lists. Minimal data required for each tree are species code, diameter, and tree expansion factor to a per acre basis. Observed crown ratio is needed but an equation is available to predict crown ratio if it is not known. Minimal data required for each tree list are site index and size in acres represented by the tree list. See the sample READ routine in Appendix I for further notes about the initial tree lists.

Processing

Processing order

In TGPS, the input subroutines SETRUN, SETVOL, and SETSYS are called first in that order to read the run options, volume coefficients, and system parameters and specifications (fig. 2). The remaining subroutines compose the Plot Processor Loop. This Loop is executed once for each tree list on the tree list input file or for a lesser number of tree lists if keyword PLOT is used.

The first action of the Plot Processor Loop is to read an initial tree list with Subroutine READ. When tree list input is complete, Subroutine TESTIT is called to examine the tree list. TESTIT checks data that are or may be entered with READ and searches for conditions likely to produce undesirable results later in the program. Informative messages are printed to describe any problems and any corrective measures that have been taken. The detail of these informative messages is controlled with keyword MESS.

Subroutine SETSI computes site index by species group based on the work by Carmean and Vasilevsky (1971) and Carmean (1979). If the species on which the plot site index was measured is not set by the READ routine, the species group with the most basal area on the plot is assumed to be the predictor species group. Site index for each of the remaining species groups is predicted by Carmean's equations. Site index for any species group for which there is no information defaults to the site index for the plot.

The next subroutine in the Plot Processor Loop is COVTYP. It sets the cover type for the plot by examining the current basal areas of the species groups present. This first call to COVTYP computes the cover type for the initial tree list.

Next Subroutine WRITER is called. This subroutine writes three types of information to the Standard Output File (discussed in a later section). The first type is plot specific information and does not change over the projection period. The second type is the current tree list, and the last type is a trailer record that indicates all output for this plot is complete. At this point within the Plot Processor Loop, only the plot specific information is written.

Subroutine WRITER is called again to write the initial tree list and stand conditions to the Standard Output File. Note that no projection has been done yet. The initial tree list written here is the same one entered with READ and is included in the output file for summarization purposes.

At this point TGPS enters the Growth and Management Loop. This Loop is executed once for each of the cycles requested by keyword CYCL. The main feature of this loop is a call to Subroutine GROW, which "grows" the plot for one cycle by applying a sequence of 1 year projections. If management is desired, it is performed at the requested point within the cycle by calls to Subroutine MANAGE. The projected tree list is written to the Standard Output File by Subroutine WRITER from within GROW.

When the Growth and Management Loop has completed all of its cycles, the projection of the current plot is complete. WRITER is called again to write a trailer record on the Standard Output File to indicate

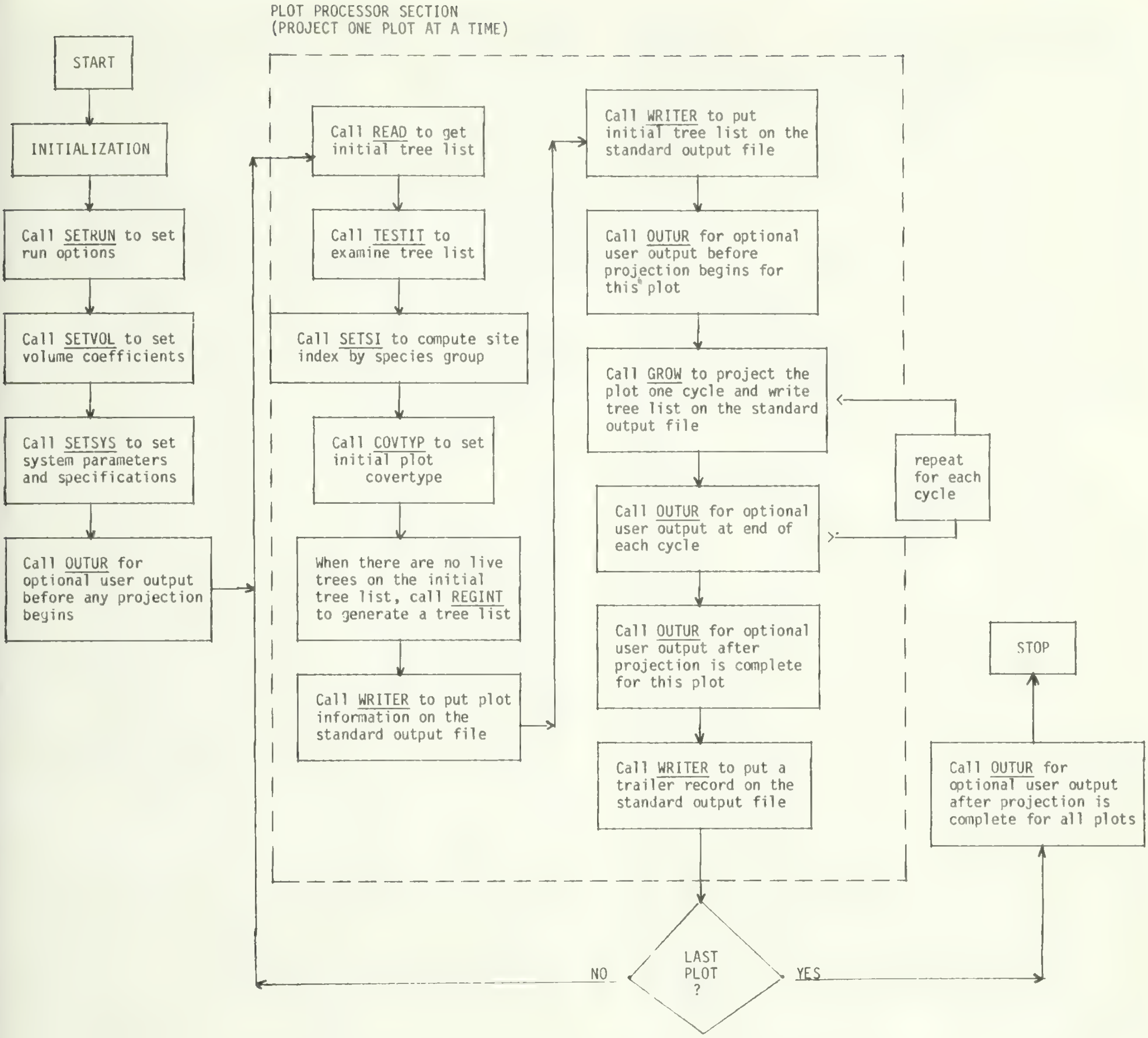
PLOT PROCESSOR SECTION
(PROJECT ONE PLOT AT A TIME)
START
INITIALIZATION
Call SETRUN to set run options
Call SETVOL to set volume coefficients
Call SETSYS to set system parameters and specifications
Call OUTUR for optional user output before any projection begins
Call READ to get initial tree list
Call TESTIT to examine tree list
Call SETSI to compute site index by species group
Call COVTYP to set initial plot covertype
When there are no live trees on the initial tree list, call REGINT to generate a tree list
Call WRITER to put plot information on the standard output file
Call WRITER to put initial tree list on the standard output file
Call OUTUR for optional user output before projection begins for this plot
Call GROW to project the plot one cycle and write tree list on the standard output file
repeat for each cycle
Call OUTUR for optional user output at end of each cycle
Call OUTUR for optional user output after projection is complete for this plot
Call WRITER to put a trailer record on the standard output file
LAST PLOT ?
NO
YES
STOP
Call OUTUR for optional user output after projection is complete for all plots

Figure 2.—*Organization of TGPS, the tree growth processor.*

the end of all tree lists for this plot. This also signals the end of the Plot Processor Loop and control returns to READ to enter the next plot to be projected.

When all the plots to be projected are complete, a final call to WRITER is made to print the format used for the Standard Output File. This is the format to be used if the user desires to summarize the Standard Output File tree lists with his own summarization program.

At several places within the program, TGPS provides calls to Subroutine OUTUR. This subroutine consists only of the common block and RETURN statement. It is intended to be a hook for insertion of user written code to do any further processing the user desires (such as summarization, output, etc.). Keyword USER sets the timing of calls to Subroutine OUTUR.

Subroutine GROW

GROW is the heart of the projection system. It projects the growth and mortality of trees by applying the projection equations and it organizes the calls to management, regeneration, and output.

The main part of GROW is the loop that projects the growth of each tree for a period of 1 year. Diameter growth is computed as the product of the potential growth and a modifier of that potential, then the tree's diameter is updated. Probability of mortality is computed, a mortality option is applied, and the tree's status is updated. After all the trees in the tree list have been projected, each tree's crown ratio is updated. This completes the projection loop. Discussions of mortality and crown ratio functions can also be found in USDA Forest Service (1979).

The projection loop within GROW is executed once for each year in the growth and management cycle. Number of years in a cycle is set with the keyword YEAR. When each year's growth is complete, Subroutine REGEN is called to add new trees to the tree list to simulate regeneration. In the current version of the Tree Growth Projection System, all aspects of regeneration have not been addressed.

Calls to the management routines are done with Subroutine MANAGE. MANAGE is called from within GROW so that management can be performed at the beginning, midpoint, or end of a cycle or at any year the user specifies with keywords MANA and CUT.

The final action of Subroutine GROW is to call WRITER to write the updated tree lists to the Standard Output File. Tree lists may be written annually or at the end of each cycle according to keyword FREQ. The option chosen will depend on the amount of detail the user desires.

Mortality

STEMS provides two options for assigning mortality to individual trees. The options are known as probabilistic and deterministic mortality and are selected by the keyword MORT. For each option, the probability of death for a tree during the coming year is computed as a function of diameter growth rate and current diameter. See USDA Forest Service (1979) for discussion of the mortality function. The difference in the two options is the way the mortality factor is applied. For probabilistic mortality, a random number between 0 and 1 is drawn and if the probability of death is greater than this random number the tree is marked as dead. Note that when a tree on the tree list dies, all the trees per acre represented by that tree also die and the tree is nullified in the tree list. For deterministic mortality, the tree's expansion factor is reduced by the proportion predicted by the mortality function. Thus, deterministic mortality can be thought of as reducing the number of trees per acre represented by a tree on the tree list. When a tree's expansion factor is reduced to 1, mortality type reverts to probabilistic so that a tree on the tree list will not represent less than one tree per acre.

Each type of mortality has its advantages and disadvantages and it is up to the user to decide which option is appropriate to his situation. For large numbers of plots and short projections, the two options produce essentially the same results. Probabilistic mortality is more computationally efficient than deterministic but for long projections it can lead to undesirable results, if a plot is reduced through mortality or cutting to two or three entries on the tree list, each tree on the list represents about one-half or one-third of the basal area on the plot. If one of these trees dies, the plot loses a large proportion of its basal area at once. This is not a reasonable representation of natural mortality. The deterministic option does not have this problem because it retains the tree list entries for a much longer period. However, more computations are necessary and annual output of tree lists is required when summary of components of growth is desired. For large numbers of plots the size of the standard output file can become critical. The probabilistic option produces a shorter output file for the same components of growth summaries.

Management subsystem

Management routines are applied from within Subroutine GROW by a call to Subroutine MANAGE. Keywords MANA and CUT allow user specification of the time of management to be: (1) before projection begins for the current cycle, (2) at the midpoint of the cycle, (3) at the end of the cycle, or (4) at any specified year or years regardless of cycle. Calls to the three management routines COVTYP, SCREEN, and TREAT are all placed within MANAGE to facilitate user modification or replacement of the subsystem.

COVTYP is caled first to determine the current cover type of the plot. It examines the basal area of each species group and assigns a cover type code based on the combination of species groups that has the most basal area. SCREEN selects the management guide and maring rule to be used based on the plot cover type and other stand variables such as age and site index. TREAT then performs the management by applying the marking rule selected by SCREEN. Trees designated as cut have their status code changed and are excluded from any further live tree computations.

A full discussion of COVTYP, SCREEN, and TREAT can be found in Brand (1981). This paper also describes the data required for the routines and discusses modifications that can be made to alter the guides.

Regeneration

Regeneration is simulated by placing new trees in the tree list. New trees can enter the tree list at three times. The first is after a clearcut when the whole tree list is to be renewed. Another is after a thinning or shelterwood cut when a portion of the tree list is to be renewed. Finally, a few trees should enter the tree list each year to simulate the natural occurrence of new seedlings. STEMS provides regeneration only for a full tree list after a clearcut. The other two types, partial regeneration and a "dribble function", are not included in STEMS at this time but are planned for future versions. Regeneration in the current version of STEMS consists of renewing the full tree list after a stand is removed by clearcutting or equivalent management action. Two subroutines, REGEN and TRLIST, are used for this process. REGEN works through a "logic tree"[3] that examines the characteristics of the previous stand and selects characteristics for the new stand. Previous stand characteristics examined are cover type, management applied, plot and species group basal areas, site index, and hydrologic regime. A block of characteristics for the new stand is selected and includes information such as the species groups present, number of trees, and average diameter for each species group.

After the new stand characteristics are determined, TRLIST is called to generate diameter distributions for the species groups on the plot. This subroutine assumes a normal distribution of diameters about an average diameter for each species group. The normal distribution is probably not the best one for modeling a regenerated stand so work is currently under way to determine a more realistic method for generating the new trees.

The management routines can result in two actions other than clearcut that trigger a full regeneration. The first is a shelterwood removal in which the overstory is removed several years after a shelterwood cut. This is essentially the same as a clearcut because there is currently no provision in STEMS to simulate the new growth that occurs after a shelterwood cut. The second action is strip clearcut in which a third of the stand is clearcut. Because STEMS cannot clearcut partial stands, every third stand designated as strip clearcut is completely clearcut and the others are unaltered. Over a large area the results are the same as if a third of each stand were clearcut.

Output

Previous versions of STEMS have included basic summarization routines within the program to perform the projections. To simplify operations and allow for easier insertion of new modules in the future, all summarization output routines have been placed in a separate program, TABL. Communication between the projection program, TGPS, and the summarization program, TABL, is done by use of a Standard Output File written by TGPS.

The Standard Output File consists of the initial and all updated tree lists for every plot in the run. These tree lists, along with an auxilliary file of system specifications, equation coefficients, and species group names, are available for input to the program TABL. These files were designed for two purposes. The first was to provide a convenient form of input for TABL. However, many users will not need the detail provided by TABL and will prefer to write their own summary routines. Therefore, a second purpose was to provide tree lists written in a simple form that would be easy to read with any FORTRAN program. This user-provided FORTRAN program could perform summaries itself or could reformat the data so it would be suitable for any of the standard statistical packages such as SPSS, BMD, SAS, or others. The tree list file and the system specification file must be saved using the procedures at your computer center so that the files can be available for later use with TABL or other programs.

The format of the Standard Output File is presented in detail in the Programmer's Guide (In preparation). An example is shown in Appendix IV.

For users with summarization goals not complex enough to require a separate summarization program, another option exists in TGPS. Subroutine OUTUR, a dummy subroutine, is provided as a hook for insertion of a user-written subroutine. Calls to OUTUR are provided at logical points within TGPS, such as at the end of each cycle for a plot or at the end of all cycles for a plot. Although OUTUR is intended for user summarization, it is not restricted to this purpose. It may be used for further processing, other user output, calls to other subroutines, or any other purpose the user desires.

---

[3] *The logic trees used in REGEN were developed by Nancy Walters and Gary Brand at NCFES. Diagrams of the logic trees are available upon request.*

TABL: SUMMARY PROGRAMS

Program TABL is a separate program provided as part of the STEMS package to produce summary tables from the Standard Output File written by TGPS. Detailed tables can be presented for each plot and for all plots in the run.

Input

Input to Program TABL consists of four separate files. First is the file of run options that provides information such as types of tables to be produced, print detail, and diameter classes to be used in the tables. The options are read as fixed format type (not keyword). The options must appear in this order and there are no defaults. Columns not used by the specified formats may be used for comments to explain the values being used. The options are:

CARD NUMBER	DEFINITION	FORMAT
1	Title: Title for these tables will be printed under the title used in TGPS.	20A4
2	ID: Run identification. Must match ID used in TGPS.	4A4
3	Echo Check: 1 = echo of system parameters used in TGPS; 0 = no echo.	I1
4	Table Type: 0 = no tables; 1 = periodic plot tables (one/cycle); 2 = projection plot tables (one/plot); 3 = run and cover type tables; 4 = 1 + 2; 5 = 2 + 3; 6 = 1 + 3; 7 = 1 + 2 + 3.	I1
5	Print Detail: 0 = species totals only (no diameter lines); 1 = species totals and diameter lines (full table); 2 = grand total only (with diameter lines).	I1
6	Diameter class limits—set by user for output classification. The lowest class is bounded below by zero. The highest class is open above. The number of classes available is set by parameter MAXD and is equal to MAXD + 1.	10F5.1
7	Diagnostic subroutine DEBUG. Code for calls to DEBUG is the same as for calls to OUTUR.	I1
8	Number of plots to process. 0 = All plots in Standard Output File.	I5
9	Units for volumes: 0 = no volume computations; 1 = biomass in cubic feet; 2 = cubic feet; 3 = board feet; 4 = cubic feet in saw logs; 5 = cords (79 cubic feet/cord).	I1
10	Standard output code: 1 = tree list input file is coded; 3 = tree list input file is binary.	I1
11	Ingrowth diameter limit for number of trees and basal area portion of table.	F4.1
12	Ingrowth diameter limit for volumes portion of table.	F4.1

The TABL run options file that produced the summary outputs shown in figure 3 is:

```
"STEMS":TABL        STANDARD OUTPUT SUMMARY PROGRAM.
                    RUN ID. SHOULD MATCH ID FROM TGPS.
1          ECHO OF SYSTEM PARAMETERS USED IN TGPS.
7          TABLE TYPE
1          PRINT DETAIL
  5.0 11.0         DIAMETER CLASS LIMITS
0          DEBUG
0          NUMBER OF PLOTS TO PROCESS. 0 MEANS ALL.
2          UNITS FOR VOLUMES
1          STD. OUTPUT FILE CODE
 5.0       DBHINT. INGROWTH LIMITS.
 5.0       DBHINV. INGROWTH LIMITS.
```

The second TABL input file is the system parameter and specification file produced by TGPS as part of the Standard Output File. The third input file holds the updated tree lists from TGPS and is also part of the Standard Output File. The last TABL input file is the same file of biomass and volume coefficients used by TGPS.

Processing

Execution of TABL begins with a call to Subroutine SETUP to read the run options, volume coefficients, and system specifications (fig. 3). Then the Plot Processor Loop is entered. First the header information for a plot is read, then a loop reads each tree list and calls the summary and table subroutines. The Plot Processor Loop is done once for each plot on the input file. After all the individual plots have been read, summarized, and tabled, run summary tables are presented both in the form of the individual plot tables and as cover type tables. The last action of Program TABL is to print a legend explaining the meaning of each of the column headings.

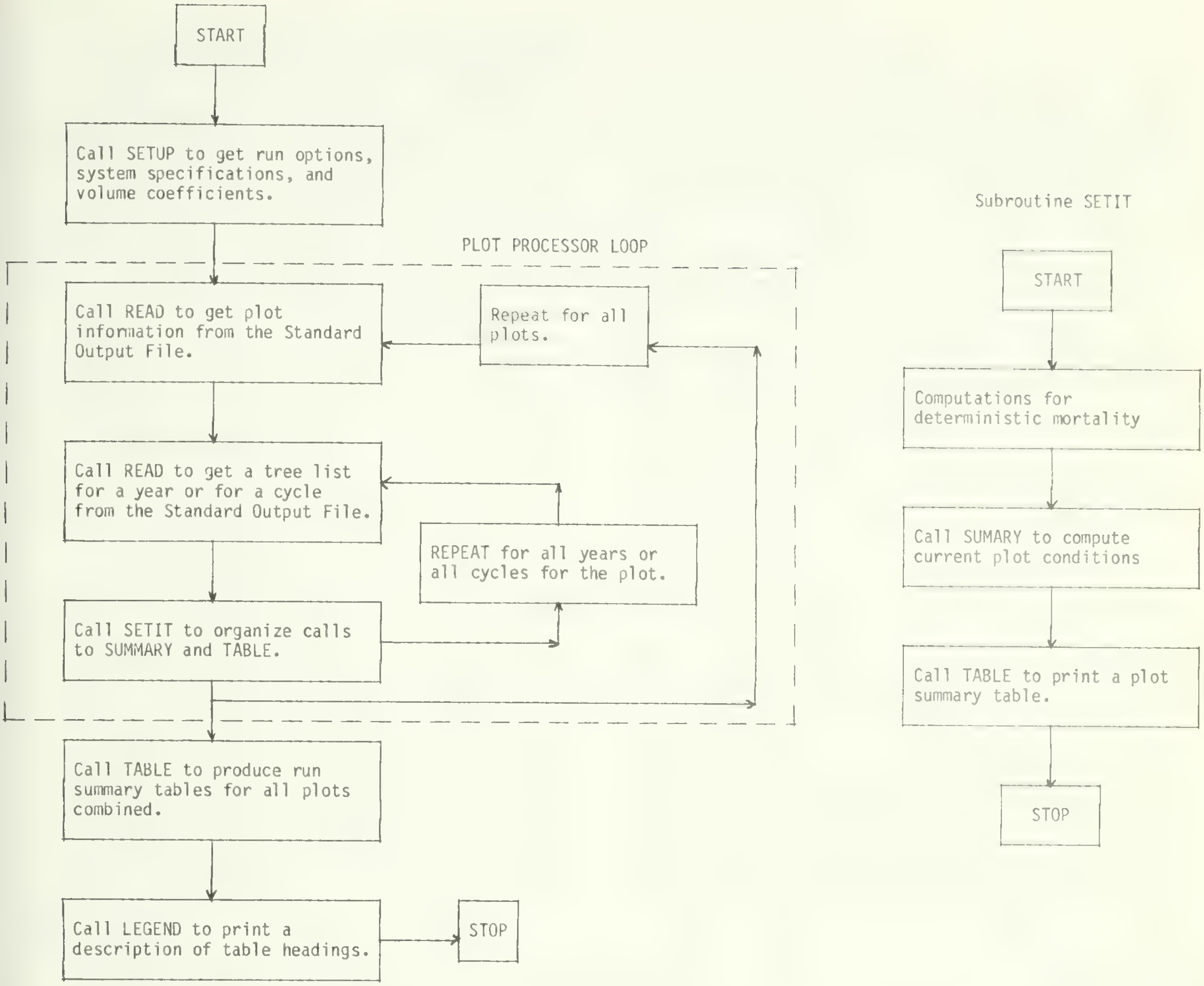
START
Call SETUP to get run options, system specifications, and volume coefficients.
PLOT PROCESSOR LOOP
Call READ to get plot information from the Standard Output File.
Repeat for all plots.
Call READ to get a tree list for a year or for a cycle from the Standard Output File.
REPEAT for all years or all cycles for the plot.
Call SETIT to organize calls to SUMMARY and TABLE.
Call TABLE to produce run summary tables for all plots combined.
Call LEGEND to print a description of table headings.
STOP
Subroutine SETIT
START
Computations for deterministic mortality
Call SUMARY to compute current plot conditions
Call TABLE to print a plot summary table.
STOP

Figure 3.—*Organization of TABL, the standard summary routine.*

Subroutine SETIT organizes the calls to the summary and table subroutines. Its first action is to compute values used in deterministic mortality summarization if that mortality option was selected in TGPS. Then Subroutine SUMARY is called to summarize current plot conditions and compute the components of growth for the plot. Subroutine TABL is then called to print the summary table. After the last plot has been summarized and tabled, tables are produced to summarize all plots together for each cycle and for all cycles.

SUMARY is the heart of the TABL program. It examines each tree in the current tree list. The number of trees per acre, basal area per acre, and volume per acre represented by each tree is assigned to the appropriate cell of the summary array by species group and by user set diameter class. This is the point at which live, dead, cut, and ingrowth trees are segregated into the appropriate categories. After each tree has been examined and summed, totals are computed by species group and by diameter class.

When summarization is complete, SETIT computes some of the values used in the table heading. Then TABL is called to print the table for the current condition of the plot. After tables for each cycle for the plot are printed, TABL is called again to print a summary of all cycles for the plot.

Output

Each output table produced by program TABL is divided into 3 sections (fig. 4a). The first section presents identification information about the plot, plot statistics, and control parameters. The definition for each term used in the heading and in the body of the table is presented in Appendix V.

The second section of the output table presents information about the number of trees and basal area broken down by species group and user-specified diameter class. For the example shown in figure 4, the plot contained two species groups: jack pine and quaking aspen. The arbitrary diameter classes were set at 0-5, 5-11, 11+ inches. The columns for initial number of trees/acre and initial basal area/acre represent stand conditions in the initial year (1980). All other columns represent conditions at the current year (1990).

Discussion of the body of this table is best done by tracing some trees through the table. For jack pine, the 0- to 5-inch class begins with 260 trees/acre. During the 10-year period represented by this table 60 trees did not cross the ingrowth limit. These trees are shown in the NON-ING column (NON-ING stands for non-ingrowth). Of the initial 260 trees in this class 40 died and appear in the MORTALITY column. At the end of the period 60 live trees remain in the 0- to 5-inch class. But 260 initial trees minus 40 mortality trees minus 60 current trees leaves 160 trees unaccounted for in the 0- to 5-inch class. These trees grew past the user-set ingrowth diameter limit (5 inches) and are shown in the INGROWTH column in the diameter class they occupied at the end of the period (5-ll inches). Note carefully the definition of ingrowth (a tree that crosses the user-set ingrowth diameter limit during this cycle). It has nothing at all to do with growth from one of the user-set diameter classes to another. The next line shows that no trees in the 5- to 11-inch class died or were cut so the 240 initial trees plus the 160 ingrowth trees equal the 400 trees currently in this class.

If a tree crosses the ingrowth limit during the period represented but dies or is cut before the current year, it will be tallied in the MORTALITY or the REMOVALS column—not in the INGROWTH column. New trees on the plot (regeneration) are not shown in this example because regeneration did not occur during this cycle. If regeneration had occurred each new tree would have been tallied in the diameter class appropriate to its diameter in the last year represented by the table. The trees cannot appear in the INITIAL column because they did not exist at the initial time. Note carefully again the definition of ingrowth. A new tree will be tallied in the INGROWTH column only if it crosses the ingrowth limit. If it does not cross the ingrowth limit and lives until the end of the cycle, it will be tallied in the NON-ING and CURRENT columns. If the regeneration tree dies or is cut before the end of the cycle, it is tallied in the MORTALITY or REMOVALS column in the diameter class it occupied at the time it died or was cut.

```
                                                                                         STEMS        80/07/31.
"STEMS": SAMPLE RUN FOR RELEASE VERSION OF THE TREE GROWTH PROJECTION SYSTEM.
"STEMS": TABL      STANDARD OUTPUT SUMMARY PROGRAM.                              PROPERTY FREP FOREST        PLOT  317 A
PLOT SUMMARY TABLE FOR CYCLE   1 OF   3
COVER TYPE      JACK PINE          PLOT SITE INDEX                     60        PLOT AREA EXPANSION FACTOR       1.
INITIAL YEAR              1980     CURRENT YEAR                      1990        ALL VALUES ARE ON A PER ACRE BASIS.
INITIAL AGE                 30     CURRENT AGE                         40        ALL VOLUMES ARE IN CUBIC FEET.
PROBABILISTIC MORTALITY USED.      AVERAGE STAND DIAMETER (INCHES)    5.6        INGROWTH DIAMETER: TREES AND BA= 5.0 INCHES.
MEAN ANNUAL INCREMENT  22.5 CUBIC FEET        PER ACRE PER YEAR.                 INGROWTH DIAMETER: VOLUMES     = 5.0 INCHES.
MANAGEMENT ACTION IN YEAR 1985: DO NOTHING

                              NUMBER OF TREES AND BASAL AREA INFORMATION.
-------------------------------------------------------------------------------------------------------------------------
SPECIES    DIAMETER   ...INITIAL..     ...NON-ING...    ..INGROWTH..     ..MORTALITY.     ..REMOVALS..     ...CURRENT..     GROWTH
 GROUP      CLASS     TREES     BA     TREES      BA    TREES      BA    TREES      BA    TREES      BA    TREES      BA     (BA)
-------------------------------------------------------------------------------------------------------------------------
JACK PINE   0.0- 5.0  260.    25.1      60.      7.1       0        0     40.      3.0       0        0     60.      7.1
            5.0-11.0  240.    41.8     240.     63.6    160.     26.8       0        0       0        0    400.     90.3
           11.0- +      0        0        0        0       0        0       0        0       0        0       0        0
           --------------------------------------------------------------------------------------------------------------
           TOTAL      500.    66.9     300.     70.7    160.     26.8     40.      3.0       0        0    460.     97.4    30.5

QUAK.ASPEN  0.0- 5.0  380.    19.7     160.     13.1       0        0    160.      5.7       0        0    160.     13.1
            5.0-11.0   20.     2.8      20.      4.8     60.      9.8       0        0       0        0     80.     14.5
           11.0- +      0        0        0        0       0        0       0        0       0        0       0        0
           --------------------------------------------------------------------------------------------------------------
           TOTAL      400.    22.5     180.     17.9     60.      9.8    160.      5.7       0        0    240.     27.6     5.1

TOTAL       0.0- 5.0  640.    44.8     220.     20.2       0        0    200.      8.7       0        0    220.     20.2
            5.0-11.0  260.    44.7     260.     68.3    220.     36.5       0        0       0        0    480.    104.8
           11.0- +      0        0        0        0       0        0       0        0       0        0       0        0
           --------------------------------------------------------------------------------------------------------------
           TOTAL      900.    89.4     480.     88.5    220.     36.5    200.      8.7       0        0    700.    125.0    35.6
#########################################################################################################################

                              VOLUME BY COMPONENTS OF GROWTH.  CUBIC FEET.
---------------------------------------------------------------------------------------------------------------------------
SPECIES    DIAMETER  INITIAL  GROWTH ON              GROWTH ON     OTHER     GROSS                NET                NET INC.  CURRENT
 GROUP      CLASS     VOLUME   NON-ING   INGROWTH  INGROWTH    GROWTH    GROWTH   MORTALITY  GROWTH   REMOVALS  INVENTORY  VOLUME
---------------------------------------------------------------------------------------------------------------------------
JACK PINE   0.0- 5.0       0         0          0          0         0         0          0         0          0          0        0
            5.0-11.0   265.3     280.4      113.5       48.8         0     442.6          0     442.6          0      442.6    707.9
           11.0- +         0         0          0          0         0         0          0         0          0          0        0
           ----------------------------------------------------------------------------------------------------------------
           TOTAL       265.3     280.4      113.5       48.8         0     442.6          0     442.6          0      442.6    707.9

QUAK.ASPEN  0.0- 5.0       0         0          0          0         0         0          0         0          0          0        0
            5.0-11.0    34.8      32.8       99.2       25.2         0     157.2          0     157.2          0      157.2    192.0
           11.0- +         0         0          0          0         0         0          0         0          0          0        0
           ----------------------------------------------------------------------------------------------------------------
           TOTAL        34.8      32.8       99.2       25.2         0     157.2          0     157.2          0      157.2    192.0

TOTAL       0.0- 5.0       0         0          0          0         0         0          0         0          0          0        0
            5.0-11.0   300.1     313.2      212.6       74.0         0     599.8          0     599.8          0      599.8    899.9
           11.0- +         0         0          0          0         0         0          0         0          0          0        0
           ----------------------------------------------------------------------------------------------------------------
           TOTAL       300.1     313.2      212.6       74.0         0     599.8          0     599.8          0      599.8    899.9

###########################################################################################################################
```

Figure 4a.—*Example of plot summary table from TABL. The definition for each term used in the heading and in the body of the table are presented in Appendix V.*

```
                                                                                                             STEMS      80/07/31.
        "STEMS": SAMPLE RUN FOR RELEASE VERSION OF THE TREE GROWTH PROJECTION SYSTEM.
        "STEMS": TABL      STANDARD OUTPUT SUMMARY PROGRAM.                              PROPERTY FREP FOREST        PLOT  317 A
        PLOT SUMMARY TABLE FOR CYCLE   2 OF    3
        COVER TYPE      JACK PINE         PLOT SITE INDEX                     60         PLOT AREA EXPANSION FACTOR       1.
        INITIAL YEAR            1990      CURRENT YEAR                      2000         ALL VALUES ARE ON A PER ACRE BASIS.
        INITIAL AGE               40      CURRENT AGE                         50         ALL VOLUMES ARE IN CUBIC FEET.
        PROBABILISTIC MORTALITY USED.     AVERAGE STAND DIAMETER (INCHES)    7.8         INGROWTH DIAMETER: TREES AND BA= 5.0 INCHES.
        MEAN ANNUAL INCREMENT  25.8 CUBIC FEET       PER ACRE PER YEAR.                  INGROWTH DIAMETER: VOLUMES     = 5.0 INCHES.
        MANAGEMENT ACTION IN YEAR 1995: THIN

                            NUMBER OF TREES AND BASAL AREA INFORMATION.
-----------------------------------------------------------------------------------------------------------------------------
SPECIES    DIAMETER   ...INITIAL..    ...NON-ING...   ..INGROWTH..    ..MORTALITY.    ..REMOVALS..    ...CURRENT..   GROWTH
 GROUP      CLASS     TREES     BA    TREES     BA    TREES     BA    TREES     BA    TREES     BA    TREES     BA   (BA)
-----------------------------------------------------------------------------------------------------------------------------
JACK PINE   0.0- 5.0   60.     7.1       0       0       0       0       0       0     20.     2.1       0       0
            5.0-11.0  400.    90.3    260.    87.5       0       0     80.    17.5    100.    17.0    260.    87.5
           11.0- +       0       0       0       0       0       0       0       0       0       0       0       0
           ------------------------------------------------------------------------------------------------------------------
           TOTAL      460.    97.4    260.    87.5       0       0     80.    17.5    120.    19.1    260.    87.5     9.2

QUAK.ASPEN  0.0- 5.0  160.    13.1       0       0       0       0     80.     5.8     60.     5.9       0       0
            5.0-11.0   80.    14.5       0       0       0       0       0       0    100.    20.6       0       0
           11.0- +       0       0       0       0       0       0       0       0       0       0       0       0
           ------------------------------------------------------------------------------------------------------------------
           TOTAL      240.    27.6       0       0       0       0     80.     5.8    160.    26.5       0       0    -1.1

TOTAL       0.0- 5.0  220.    20.2       0       0       0       0     80.     5.8     80.     8.0       0       0
            5.0-11.0  480.   104.8    260.    87.5       0       0     80.    17.5    200.    37.6    260.    87.5
           11.0- +       0       0       0       0       0       0       0       0       0       0       0       0
           ------------------------------------------------------------------------------------------------------------------
           TOTAL      700.   125.0    260.    87.5       0       0    160.    23.2    280.    45.6    260.    87.5     8.1
#############################################################################################################################

                            VOLUME BY COMPONENTS OF GROWTH.  CUBIC FEET.
---------------------------------------------------------------------------------------------------------------------------------
SPECIES    DIAMETER   INITIAL GROWTH ON           GROWTH ON     OTHER    GROSS                 NET             NET INC.   CURRENT
 GROUP      CLASS      VOLUME   NON-ING  INGROWTH INGROWTH     GROWTH    GROWTH MORTALITY    GROWTH  REMOVALS INVENTORY    VOLUME
---------------------------------------------------------------------------------------------------------------------------------
JACK PINE   0.0- 5.0        0         0         0         0         0         0         0         0         0         0         0
            5.0-11.0    707.9     345.4         0         0      86.7     432.1     134.1     298.0     104.4     193.6     901.5
           11.0- +          0         0         0         0         0         0         0         0         0         0         0
           ----------------------------------------------------------------------------------------------------------------------
           TOTAL        707.9     345.4         0         0      86.7     432.1     134.1     298.0     104.4     193.6     901.5

QUAK.ASPEN  0.0- 5.0        0         0         0         0         0         0         0         0         0         0         0
            5.0-11.0    192.0         0         0         0      90.6      90.6         0      90.6     282.5    -192.0         0
           11.0- +          0         0         0         0         0         0         0         0         0         0         0
           ----------------------------------------------------------------------------------------------------------------------
           TOTAL        192.0         0         0         0      90.6      90.6         0      90.6     282.5    -192.0         0

TOTAL       0.0- 5.0        0         0         0         0         0         0         0         0         0         0         0
            5.0-11.0    899.9     345.4         0         0     177.3     522.7     134.1     388.6     386.9       1.6     901.5
           11.0- +          0         0         0         0         0         0         0         0         0         0         0
           ----------------------------------------------------------------------------------------------------------------------
           TOTAL        899.9     345.4         0         0     177.3     522.7     134.1     388.6     386.9       1.6     901.5

#################################################################################################################################
```

Figure 4b.—*Example of plot summary table from TABL.*

The third section of the output table presents volumes by the same species group and diameter class breakdowns as above. This section can be omitted if not needed by specifying the units for volumes as 0. Initial volume is the volume at the initial year (1980) for this table. The volumes for this example are in cubic feet and were produced using volume equations supplied by the Resources Evaluation Unit at the North Central Forest Experiment Station. The lower limit for these equations is 5 inches so all volumes in the 0-5 inch class show as zeros. The 200 trees that died during this cycle had no volume according to these equations. Volume information can be developed for each of the available units through repeated runs of TABL.

Of special note is the fact that the ingrowth columns for the volume summary in the third section may not represent the same trees as the ingrowth columns of the upper portion of this table. For this example they are equivalent because both ingrowth diameter limits are equal to the same value (5 inches). However, a user may want to set the ingrowth limit for the trees and basal area table to zero so that all regeneration will show up in the INGROWTH column while leaving the ingrowth limit for volume equal to the lower limit for the volume equations.

Figure 4b represents the second growth cycle for this example plot. A thinning occurred in 1995. The body of the table shows that 120 jack pine trees and 160 quaking aspen trees were cut. In terms of plot basal area, this example stand began with 125.0 square feet in 1990, grew until 1995, was reduced by 45.6 square feet in 1995, grew until the current year, 2000, and completed the cycle with 87.5 square feet. Current (87.5 square feet) plus removals (45.6 square feet) minus initial (125.0 square feet) equals the basal area growth for this plot during this cycle (8.1 square feet). Note that all numbers in this table are subject to round off error.

Appendix V explains the computations used to determine the volume of each of the components of growth. For this example the computations are:

	CUBIC FEET
GROWTH-ON NON-ING	345.4
+	+
INGROWTH	0
+	+
GROWTH ON INGROWTH	0
+	+
GROWTH ON MORTALITY	
+	177.3
GROWTH ON REMOVALS	
=	=
GROSS GROWTH	522.7
−	−
MORTALITY	134.1
=	=
NET GROWTH	388.6
−	−
REMOVALS	386.9
=	=
NET INCREASE IN INVENTORY	1.6
+	+
INITIAL VOLUME	899.9
=	=
CURRENT VOLUME	901.5

The examples shown in figures 4a and 4b are plot summary tables for cycles 1 and 2 for a single plot. After all plots on the input file have been projected, a summary is run for all plots combined and is printed in the same format as the plot summary tables. All column headings have the same meanings but the table entries are scaled differently—the plot summaries are presented on a per acre basis and the run summaries present total values for the area the plots represent. For example, when a survey is made in which each sample plot represents 50 acres of forest, the "plot area expansion factor" will be set at 50 (using variable APRLOC in the user written READ routine). In this case the values in the table will be the total number of trees, total basal area, and total volume on the area surveyed.

Run summaries are printed for each cycle and for all cycles combined. A summary by cover type accompanies each run summary.

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APPENDIX I.

Sample READ Routine for TGPS

This section presents a sample subroutine for reading the initial tree lists that will be projected by TGPS. This subroutine may be used as an example for the subroutine the user must write to read his own data file. This subroutine and sample input file were written by Stephen R. Shifley at the North Central Forest Experiment Station (NCFES). The comments within the FORTRAN source code discuss requirements for the input data and the processing required in the READ routine.

For users who prefer to reformat their data rather than write a new READ routine, the format used in the sample READ routine is presented here. Each plot (each tree list) requires three types of data records: one header record, a tree detail record for each tree, and one trailer record. The header record layout is:

Data	Column	Format
Property	1-16	4A4
Plot name	17-24	2A4
Plot covertype	25-27	I3
Plot site index	28-30	I3
(not used)	31-37	
Year of plot origin	38-42	I5

The tree detail record layout is:

Data	Column	Format
Property name	1-16	4A4
Plot name	17-24	2A4
(not used)	25-27	
Tree Status	28-29	I2
USDA Forest Service species code	30-33	F4.0
Diameter	34-37	F4.1

The Trailer record consists of only one card with a blank in column 1 and the word "END" in columns 2-4.

This READ routine assumes the initial year of projection is 1980 and each sample tree represents 20 trees per acre. The routine is accessed by specifying keyword READ as 2.

```
      SUBROUTINE READ
C
C
C***********************************************************************
C
C    SUBROUTINE "READ" READS AND STORES THE INITIAL PLOT AND TREE
C    INFORMATION UPON WHICH THE PROJECTION OR UPDATE WILL BE
C    BASED.  BECAUSE IT IS ANTICIPATED THAT NO TWO USERS WILL
C    HAVE IDENTICALLY FORMATTED INPUT DATA, THE CREATION OF
C    THE "READ" SUBROUTINE IS GENERALLY LEFT TO THE INDIVIDUAL.
C    IT IS PERMISSIBLE TO INCLUDE ANY VARIETY OF FORTRAN CONTORTIONS
C    IN THE "READ" SUBROUTINE PROVIDED THAT:
C
C      (1)  NO PREVIOUSLY ASSIGNED VARIABLE NAMES ARE USED.
C           (ALL PREVIOUSLY ASSIGNED VARIABLE NAMES ARE LISTED
C           IN THE DATA DICTIONARY WHICH IS SUPPLIED WHEN THE USER
C           REQUESTS A MAGNETIC TAPE COPY OF THE STEMS SYSTEM)
C      (2)  EVENTUALLY THE PROPER AND NECESSARY VALUES FOR THE
C           VARIABLE MEA AND THE ARRAYS TRS, ITRS, IP, IYR, AND BAPY
C           ARRIVE IN THEIR SPECIFIED LOCATIONS.
C
C
C    THE FOLLOWING IS AN EXAMPLE OF A SIMPLE "READ" SUBROUTINE
C    FOR USE WITH A SPECIFIC DATA FILE.  HOPEFULLY, THIS EXAMPLE
C    WILL SERVE AS A GUIDE FOR THOSE WHO WRITE THEIR OWN "READ"
C    SUBROUTINES.
C
C    IN THIS EXAMPLE IT IS ASSUMED THAT THE PLOT AND TREE INFORMATION
C    WILL BE READ FROM A FILE CALLED "TAPE11".  (WITH MINOR MODIFICA-
C    TIONS THIS DATA COULD ALSO BE READ FROM CARD INPUT.)  IT IS FURTHER
C    ASSUMED THAT EACH PLOT RECORD CONSISTS OF A PLOT HEADER
C    CARD IMAGE FOLLOWED BY ONE TREE DETAIL CARD IMAGE FOR EACH TREE
C    ON THE PLOT.  THE END OF EACH PLOT IS DENOTED BY A TRAILER CARD
C    IMAGE WITH " END" IN THE FIRST FOUR COLUMNS.
C
C
C    THE FOLLOWING VARIABLES ARE USED IN THIS EXAMPLE OF "READ":
C
C    APRLOC = AREA IN ACRES REPRESENTED BY THIS PLOT.
C    BAPY(1)= PLOT BASAL AREA PER ACRE.
C    BASUM  = RUNNING TOTAL PLOT BASAL AREA PER ACRE.
C    CR     = TREE CROWN RATIO.
C    DBH    = TREE DIAMETER AT BREAST HEIGHT.
C    I      = TREE COUNTER FOR EACH PLOT AND SERVES TO INDEX
C             TRS AND ITRS ARRAYS.
C    INPLTS = SPECIFIED NUMBER OF PLOTS TO BE READ AS INPUT.
C    ISG    = FREP SPECIES GROUP TO WHICH A TREE BELONGS.
C    ISP(J) = ARRAY, INDEX IS SPECIES CODE, VALUE IS FREP SPECIES GROUP.
```

```
C    ISW1   = SWITCH TO INDICATE END OF A PLOT AND OF ALL PLOTS.
C         ISW1=0 INDICATES LAST PLOT HAS NOT YET BEEN REACHED.
C         ISW1=2 INDICATES LAST PLOT HAS BEEN READ BUT NOT PROCESSED.
C         ISW1=3 INDICATES LAST PLOT HAS BEEN READ AND PROCESSED.
C    IYR(K) = ARRAY HOLDING INITIAL PROJECTION YEAR AND YEAR WHICH
C             ENDS EACH CYCLE.  NOTE THAT ALL YEARS USED IN
C             STEMS MUST BE SPECIFIED IN 4-DIGIT FORM, I.E., 1975 NOT 75.
C    J      = AN INDEX VARIABLE EQUAL TO SPECIES CODE.
C    KPLOT  = PLOT NUMBER OR NAME.
C    KPROP  = PROPERTY NUMBER OR NAME.
C    MEA    = NUMBER OF CYCLES + 1.
C    NORIG  = YEAR OF PLOT ORIGIN.
C    NPLOTS = NUMBER OF PLOTS THAT HAVE BEEN READ FROM DATA FILE.
C    NSITE  = PLOT SITE INDEX.
C    NST    = NUMBER OF TREES (STEMS) IN THE TRS/ITRS ARRAYS.
C    NSTAT  = TREE STATUS CODE.
C    NTYPE  = PLOT COVER TYPE CODE.
C    SPP    = TREE SPECIES CODE.
C    TREEBA = INDIVIDUAL TREE BASAL AREA.
C
C    IP ARRAY:
C      IP(1)  = NUMBER OF TREES IN TRS/ITRS ARRAYS (EQUAL TO NST)
C      IP(5)  = INITIAL PLOT BASAL AREA PER ACRE
C      IP(8)  = PLOT FOREST TYPE
C      IP(9)  = PLOT SITE INDEX
C      IP(10) = PLOT AGE
C      IP(18) = INITIAL YEAR OF PROJECTION/VALIDATION
C
C    ITRS ARRAY WHEN I INDICATES THE ITH TREE ON A PLOT:
C      ITRS(I,1) = TREE STATUS (1=LIVE, 2=CUT, 3=MORTALITY)
C      ITRS(I,7) = TREE CLASS AS NEEDED FOR VOLUME EQUATIONS
C
C    TRS ARRAY WHEN I INDICATES THE ITH TREE ON A PLOT:
C      TRS(I,1)  = TREE SPECIES CODE
C      TRS(I,2)  = TREE DBH
C      TRS(I,3)  = TREE CROWN RATIO
C      TRS(I,5)  = TREE CROWN RATIO CORRECTION FACTOR
C                  (OBSERVED CROWN RATIO - CALCULATED CROWN RATIO)
C      TRS(I,7)  = SET EQUAL TO TRS(I,2), INITIAL TREE DBH
C      TRS(I,13) = TREE EXPANSION FACTOR (TO PER ACRE)
C      TRS(I,16) = BASAL AREA EXPANSION FACTOR (TO PER ACRE)
C
C***********************************************************************
C
      DATA IEND / 4H END /
```

```
C
C***********************************************************************
C    SET 1980 AS THE INITIAL YEAR OF THE PROJECTION.
C    IF DESIRED, THE INITIAL YEAR OF PROJECTION COULD BE READ
C    FOR EACH NEW STEMS RUN, RATHER THAN FIXED AS IT IS HERE.
C***********************************************************************
      DUMMY=0.0
      IYR(1) = 1980
      IP(18) = IYR(1)
C
C***********************************************************************
C    FROM THE PREVIOUSLY READ AND DEFINED "RUN PARAMETERS" IT
C    IS KNOWN THAT NP(3) IS THE NUMBER OF CYCLES AND NP(2) IS
C    THE NUMBER OF YEARS IN EACH CYCLE.  EACH CYCLE MAY BE THOUGHT
C    OF AS A SUMMARY OR MANAGEMENT CYCLE.  MEA IS SET BY
C    DEFINITION TO BE ONE PLUS THE NUMBER OF CYCLES.  THE VALUES IN
C    THE CELLS OF THE ARRAY IYR THAT FOLLOW IYR(1) ARE SEQUENTIALLY
C    SET TO THE YEAR CORRESPONDING TO THE END OF EACH CYCLE.
C
C    NOTE THAT THE ELEMENTS OF IYR() MAY BE ASSIGNED INDIVIDUALLY
C    RATHER THAN IN A LOOP TO ALLOW FOR UNEQUAL LENGTH CYCLES.
C    WHEN THIS PROCESS IS APPLIED, THE USER MUST ENSURE THAT
C    MEA IS SET TO THE NUMBER OF ELEMENTS IN IYR() AND THE
C    NUMBER OF CYCLES IS SET TO MEA - 1.
C***********************************************************************
      MEA = NP(3) + 1
      DO 5 K=2,MEA
    5 IYR(K) = IYR(K-1) + NP(2)
C
C***********************************************************************
C    READ A PLOT HEADER CARD IMAGE AND CHECK TO SEE IF THE
C    END OF THE FILE HAS BEEN REACHED.
C***********************************************************************
   10 READ(11,100,END=38)KPROP,KPLOT,NTYPE,NSITE,NORIG
  100 FORMAT(4A4,2A4,2I3,7X,I5)
      IF(EOF(11).NE.0.0) GO TO 38
C
C***********************************************************************
C    FILL THE APPROPRIATE CELLS IN THE IP ARRAY WITH THE VALUES
C    FOR FOREST TYPE AND SITE INDEX.  IT IS
C    ASSUMED THAT THE FOREST TYPE CODES USED ON THE DATA FILE
C    ARE THE RECOGNIZED STEMS FOREST TYPE CODES.  IF NOT,
C    FOREST TYPE CODES MUST BE CONVERTED TO THOSE RECOGNIZED
C    BY STEMS.  IF SITE INDEX IS NOT INCLUDED ON A PLOT HEADER
C    CARD, IT IS ASSUMED TO BE 70.
C***********************************************************************
      IP(8) = NTYPE
      IP(9) = NSITE
      IF(NSITE.LE.0) IP(9)=70
```

```
C
C*********************************************************************
C    DETERMINE STAND AGE, IP(10), FROM THE DATE OF STAND ORIGIN.
C    NOTE THAT STAND AGE IS NECESSARY ONLY FOR
C    CERTAIN MANAGEMENT ROUTINES IN SUBROUTINE SCREEN.
C*********************************************************************
      IP(10) = IYR(1) - NORIG
C
C*********************************************************************
C    INITIALIZE THE COMBINATION TREE COUNTER AND INDEX VARIABLE, I.
C    INITIALIZE THE BASAL AREA PER ACRE ACCUMULATOR, BASUM.
C*********************************************************************
      I = 1
      BASUM = 0.0
C
C*********************************************************************
C    READ A TREE DETAIL CARD IMAGE AND CHECK FOR THE PLOT
C    TRAILER CARD.
C*********************************************************************
   15 READ(11,200)KPROP,KPLOT,NSTAT,SPP,DBH
  200 FORMAT(4A4,2A4,3X,I2,F4.0,F4.1)
      IF(KPROP(1).EQ.IEND) GO TO 25
C
C*********************************************************************
C    SAVE TREE STATUS IN APPROPRIATE CELL OF ITRS ARRAY.  IT IS
C    ASSUMED THAT THE STATUS CODES PROVIDED WILL BE ONLY THOSE
C    THAT STEMS RECOGNIZES.  WHEN THIS IS NOT THE CASE, FOREIGN
C    STATUS CODES MUST BE CONVERTED TO THOSE USED BY STEMS.
C    ONLY LIVE TREES ARE PROJECTED--OTHERS ARE IGNORED.  IN THIS
C    EXAMPLE, TREES WITH STATUS CODE 4 ARE REASSIGNED A STATUS
C    CODE OF 1 BECAUSE STEMS ONLY RECOGNIZES
C    STATUS CODES 1, 2, AND 3.  THE INPUT DATA SET USES A
C    STATUS CODE OF 4 TO SIGNIFY A NEW TREE ON THE PLOT.
C*********************************************************************
      IF(NSTAT.EQ.1.OR.NSTAT.EQ.4) GO TO 20
      GO TO 15
   20 ITRS(I,1) = NSTAT
      IF(NSTAT.EQ.4) ITRS(I,1)=1
C
C*********************************************************************
C    PLACE THE TREE SPECIES CODE IN THE APPROPRIATE CELL OF THE
C    TRS ARRAY AND ASSIGN A FREP SPECIES GROUP (ISG) BY USING
C    THE CONVERSION ARRAY ISP() THAT WAS SET IN SUBROUTINE
C    SETSYS. NOTE THAT SPECIES CODE IS USED ONLY FOR THIS
C    CONVERSION BUT SPECIES GROUP IS USED THROUGHOUT STEMS
C    FOR PROJECTION AND SUMMARIZATION.  IF THE DATA SET
C    CONTAINS FREP SPECIES GROUPS, THE READ ROUTINE MAY
C    BE ALTERED TO READ ISG DIRECTLY.
C*********************************************************************
      TRS(I,1) = SPP
      ISPG= SPP
      ISG= ISP(ISPG)
      ITRS(I,3)= ISG
```

```
C
C*********************************************************************
C    SAVE DBH AND PLOT EXPANSION FACTOR, CALCULATE BASAL AREA
C    AND THE TREE'S BASAL AREA EXPANSION FACTOR.  ALL PLOTS ARE
C    ONE-SEVENTH ACRE IN THIS EXAMPLE.
C*********************************************************************
      TRS(I,2) = DBH
      TRS(I,7) = DBH
      TREEBA = 0.005454 * (DBH ** 2)
      TRS(I,13) = 7.
      TRS(I,16) = TRS(I,13) * TREEBA
C
C*********************************************************************
C    DETERMINE TREE CLASS TO BE USED IN VOLUME CALCULATIONS.
C    IN ABSENCE OF ANY TREE CLASS INFORMATION, ALL TREES
C    GREATER THAN TWENTY INCHES DBH WILL BE ASSIGNED A TREE
C    CLASS OF 20, AND ALL OTHER TREES WILL BE ASSIGNED A
C    TREE CLASS OF 10. TREE CLASS IS USED ONLY FOR VOLUME COMPUTATIONS.
C*********************************************************************
      ITRS(I,7) = 10
      IF(TRS(I,2).GT.20.0) ITRS(I,7) = 20
C
C*********************************************************************
C    ACCUMULATE BASAL AREA PER ACRE.
C*********************************************************************
      BASUM = BASUM + TRS(I,16)
C
C*********************************************************************
C    INCREMENT TREE COUNTER AND RETURN TO READ THE NEXT TREE
C    RECORD
C*********************************************************************
      I = I + 1
      GO TO 15
C
C
C*********************************************************************
C*********************************************************************
C    END OF A PLOT RECORD.
C    SAVE TOTAL NUMBER OF TREES ON PLOT AS IP(1).
C*********************************************************************
   25 IP(1) = I - 1
      NST = I - 1
C
C*********************************************************************
C    SAVE THE BASAL AREA PER ACRE AS IP(5) AND BAPY(1).
C*********************************************************************
      IP(5) = BASUM
      BAPY(1) = BASUM
```

```
C
C***********************************************************************
C    BECAUSE CROWN RATIO DATA WERE NOT PROVIDED ON TAPE11, THE
C    ESTIMATED CROWN RATIO FOR EACH TREE ON A PLOT WILL BE
C    COMPUTED VIA THE STEMS CROWN RATIO FUNCTION.  THE CROWN
C    RATIO IS COMPUTED BY A CALL TO THE FUNCTION SUBPROGRAM
C    "VALUE".
C***********************************************************************
      DO 30 I=1,NST
      ISG = ITRS(I,3)
      CR = VALUE(1,ISG,TRS(I,2),BASUM,0.0,DUMMY)
      TRS(I,3) = CR
C
C***********************************************************************
C    THE CROWN RATIO CORRECTION FACTOR IS THE DIFFERENCE BETWEEN
C    THE OBSERVED AND PREDICTED CROWN RATIOS.  BECAUSE NO CROWN
C    RATIOS WERE OBSERVED, ALL VALUES OF TRS(I,5) WILL BE
C    SET TO ZERO.
C***********************************************************************
      TRS(I,5) = 0.0
   30 CONTINUE
C
C***********************************************************************
C    SET SWITCH TO INDICATE END OF A PLOT AND CHECK TO SEE IF
C    THE END OF ALL PLOTS HAS BEEN REACHED.
C***********************************************************************
      NPLOTS = NPLOTS + 1
      IF(INPLTS.EQ.NPLOTS.AND.INPLTS.NE.0) GO TO 35
      GO TO 40
C
C***********************************************************************
C    RESET SWITCH TO INDICATE THAT THE LAST PLOT HAS BEEN READ.
C***********************************************************************
   35 ISW1 = 2
      GO TO 40
C
C***********************************************************************
C    RESET SWITCH TO INDICATE THAT THE LAST PLOT HAS BEEN COMPLETED.
C***********************************************************************
C
   38 ISW1= 3
   40 RETURN
      END
```

SAMPLE TREE LIST INPUT FILE
FOR THE EXAMPLE PRESENTED IN
THIS USER'S GUIDE.

```
FREP FOREST     317 A      2 60          1950
FREP FOREST     317 A      1 1 105   30
FREP FOREST     317 A      2 1 105   33
FREP FOREST     317 A      3 1 105   35
FREP FOREST     317 A      4 1 105   43
FREP FOREST     317 A      5 1 105   43
FREP FOREST     317 A      6 1 105   40
FREP FOREST     317 A      7 1 105   41
FREP FOREST     317 A      8 1 105   44
FREP FOREST     317 A      9 1 105   47
FREP FOREST     317 A     10 1 105   48
FREP FOREST     317 A     11 1 105   45
FREP FOREST     317 A     12 1 105   47
FREP FOREST     317 A     13 1 105   46
FREP FOREST     317 A     14 1 105   53
FREP FOREST     317 A     15 1 105   54
FREP FOREST     317 A     16 1 105   52
FREP FOREST     317 A     17 1 105   50
FREP FOREST     317 A     18 1 105   54
FREP FOREST     317 A     19 1 105   50
FREP FOREST     317 A     20 1 105   57
FREP FOREST     317 A     21 1 105   58
FREP FOREST     317 A     22 1 105   60
FREP FOREST     317 A     23 1 105   59
FREP FOREST     317 A     24 1 105   66
FREP FOREST     317 A     25 1 105   63
FREP FOREST     317 A     26 1 741   11
FREP FOREST     317 A     27 1 741   13
FREP FOREST     317 A     28 1 741   13
FREP FOREST     317 A     29 1 741   22
FREP FOREST     317 A     30 1 741   27
FREP FOREST     317 A     31 1 741   26
FREP FOREST     317 A     32 1 741   26
FREP FOREST     317 A     33 1 741   25
FREP FOREST     317 A     34 1 741   28
FREP FOREST     317 A     35 1 741   34
FREP FOREST     317 A     36 1 741   33
FREP FOREST     317 A     37 1 741   34
FREP FOREST     317 A     38 1 741   31
FREP FOREST     317 A     39 1 741   32
FREP FOREST     317 A     40 1 741   38
FREP FOREST     317 A     41 1 741   40
FREP FOREST     317 A     42 1 741   36
FREP FOREST     317 A     43 1 741   43
FREP FOREST     317 A     44 1 741   45
FREP FOREST     317 A     45 1 741   51
 END
COOK COUNTY     BACK 40    2 80 125   0 1947 1970
COOK COUNTY     BACK 40    1 1 105   45 1 0
COOK COUNTY     BACK 40    2 1 105   46 1 0
COOK COUNTY     BACK 40    3 1 105   48 1 0
COOK COUNTY     BACK 40    4 1 105   49 0 0
COOK COUNTY     BACK 40    5 1 105   40 1 0
COOK COUNTY     BACK 40    6 1 105   40 1 0
COOK COUNTY     BACK 40    7 1 105   50 1 0
COOK COUNTY     BACK 40    8 2 105    0 1 0
COOK COUNTY     BACK 40    9 2 105    0 1 0
COOK COUNTY     BACK 40   10 2 105    0 1 0
COOK COUNTY     BACK 40   11 2 105    0 1 0
COOK COUNTY     BACK 40   12 2 105    0 1 0
COOK COUNTY     BACK 40   13 2 105    0 1 0
COOK COUNTY     BACK 40   14 2 105    0 1 0
COOK COUNTY     BACK 40   15 2 105    0 1 0
COOK COUNTY     BACK 40   16 2 105    0 1 0
COOK COUNTY     BACK 40   17 2 105    0 1 0
COOK COUNTY     BACK 40   18 2 105    0 1 0
COOK COUNTY     BACK 40   19 2 105    0 1 0
COOK COUNTY     BACK 40   20 2 105    0 1 0
COOK COUNTY     BACK 40   21 2 105    0 1 0
COOK COUNTY     BACK 40   22 2 105    0 1 0
COOK COUNTY     BACK 40   23 2 105    0 1 0
COOK COUNTY     BACK 40   24 2 105    0 1 0
COOK COUNTY     BACK 40   25 2 105    0 1 0
COOK COUNTY     BACK 40   26 2 105    0 1 0
COOK COUNTY     BACK 40   27 2 105    0 1 0
COOK COUNTY     BACK 40   28 2 105    0 1 0
COOK COUNTY     BACK 40   29 2 105    0 1 0
COOK COUNTY     BACK 40   30 2 105    0 1 0
COOK COUNTY     BACK 40   31 2 105    0 1 0
COOK COUNTY     BACK 40   32 2 105    0 1 0
COOK COUNTY     BACK 40   33 2 105    0 1 0
COOK COUNTY     BACK 40   34 2 105    0 1 0
COOK COUNTY     BACK 40   35 1 105   63 0 0
COOK COUNTY     BACK 40   36 1 125   87 0 0
COOK COUNTY     BACK 40   37 2 105    0 1 0
COOK COUNTY     BACK 40   38 2 105    0 1 0
COOK COUNTY     BACK 40   39 1 125   60 0 3
COOK COUNTY     BACK 40   40 1 125   68 0 0
COOK COUNTY     BACK 40   41 1 105   73 0 0
COOK COUNTY     BACK 40   42 1 105   67 0 0
COOK COUNTY     BACK 40   43 1 125   62 0 3
COOK COUNTY     BACK 40   44 1 125   64 0 2
COOK COUNTY     BACK 40   45 1 105   60 0 0
COOK COUNTY     BACK 40   46 1 125   62 0 0
COOK COUNTY     BACK 40   47 1 105   58 0 0
COOK COUNTY     BACK 40   48 1 105   58 0 0
COOK COUNTY     BACK 40   49 1 105   61 0 0
COOK COUNTY     BACK 40   50 1 125   72 0 2
COOK COUNTY     BACK 40   51 1 105   60 0 0
COOK COUNTY     BACK 40   52 1 125   77 0 3
COOK COUNTY     BACK 40   53 1 105   59 0 0
COOK COUNTY     BACK 40   54 1 105   61 0 0
COOK COUNTY     BACK 40   55 1 105   58 0 0
COOK COUNTY     BACK 40   56 1 125   67 0 0
COOK COUNTY     BACK 40   57 1 105   53 0 0
COOK COUNTY     BACK 40   58 1 125   94 0 2
COOK COUNTY     BACK 40   59 1 105   64 0 0
COOK COUNTY     BACK 40   60 4 125   51 9 3
COOK COUNTY     BACK 40   61 4 105   53 9 0
COOK COUNTY     BACK 40   62 4 125   55 9 0
COOK COUNTY     BACK 40   63 4 105   51 9 0
COOK COUNTY     BACK 40   64 4 105   51 9 0
COOK COUNTY     BACK 40   65 4 105   54 9 0
COOK COUNTY     BACK 40   66 4 125   65 9 2
COOK COUNTY      BACK 40  67 4 105   51 9 0
COOK COUNTY      BACK 40  68 4 125   65 9 2
COOK COUNTY      BACK 40  69 4 125   60 9 0
COOK COUNTY      BACK 40  70 4 125   64 9 3
COOK COUNTY      BACK 40  71 4 125   57 9 3
COOK COUNTY      BACK 40  72 4 125   51 9 3
COOK COUNTY      BACK 40  73 4 125   51 9 0
COOK COUNTY      BACK 40  74 4 105   52 9 0
COOK COUNTY      BACK 40  75 4 125   54 9 0
 END
BACON COUNTY     LOWER 40 12 52 316   0 1933 1970
BACON COUNTY     LOWER 40  1 3  95    0 2 0
BACON COUNTY     LOWER 40  2 1 746   68 0 4
BACON COUNTY     LOWER 40  3 1  95  106 0 2
BACON COUNTY     LOWER 40  4 3 316    0 2 0
BACON COUNTY     LOWER 40  5 1  95   71 0 2
BACON COUNTY     LOWER 40  6 1  95   69 0 2
BACON COUNTY     LOWER 40  7 1 316   60 0 4
BACON COUNTY     LOWER 40  8 1 746   74 0 3
BACON COUNTY     LOWER 40  9 1  12   53 0 2
BACON COUNTY     LOWER 40 10 1 375   69 0 2
BACON COUNTY     LOWER 40 11 1 316   69 0 2
BACON COUNTY     LOWER 40 12 1 375   61 0 3
BACON COUNTY     LOWER 40 13 1 375   64 0 3
BACON COUNTY     LOWER 40 14 4 375   50 9 2
BACON COUNTY     LOWER 40 15 4 316   56 9 4
BACON COUNTY     LOWER 40 16 4  95   50 9 3
BACON COUNTY     LOWER 40 17 4 375   51 9 2
BACON COUNTY     LOWER 40 18 4 316   50 9 4
BACON COUNTY     LOWER 40 19 4 375   52 9 4
 END
```

APPENDIX II.

Volume and Biomass Equations and Coefficients

The volume equation used for the example in this User's Guide was developed for northeastern Minnesota by the North Central Forest Experiment Station's Resources Evaluation Project (Raile 1981). The equation estimates individual tree volume and has the form:

$$\text{Volume} = b_0 SI(1-e^{-b_1 DBH})^{b_2}$$

where: SI = plot site index (in feet);
DBH = diameter at breast height (in inches); and
b_0, b_1, b_2 are regression
coefficients specific to species group,
tree class, and the units used for volume.

The biomass equation [1] was also developed for northeastern Minnesota by the Station's Resources Evaluation Project. The equation estimates individual tree biomass in cubic feet and has the form:

$$\text{BIOMASS} = \text{BOBAWT/BARKWT} + \text{VOLG} + \text{TOPWT/WT}_i$$

where BOBAWT = bole bark weight;
= VOLG X BARKWT X (1.1646 - SCF)
BARKWT = bark weight = 37 pounds/cubic foot;
SCF = species correction factor
= $a_0 + a_1$ DBH;
WT_i = weight factor for species group_i;
VOLG = gross bole volume in cubic feet;
= $b_0 SI(1-e^{-b_1 DBH})^{b_2}$
SI = plot site index (in feet);
DBH = diameter at breast height (in inches);
TOPWT = top weight;
= 0.4545 (BOBAWT + VOLG X SCF X WT_i); and
a_0, a_1, b_0, b_1, b_2 are regression coefficients.

The first 62 lines in the coefficient data set show the regression coefficients used for biomass computations. The 63rd line holds a State code which determines which volume equation will be used. The STEMS system at FCCC has equations for Minnesota (discussed above) and for Wisconsin (Hahn 1973). The State codes are 27 and 55 for Minnesota and Wisconsin respectively. The remaining lines hold the regression coefficients for the volume equation.

```
 1 .38799680E+04 .13200139E-02 .23002443E+01  50   MN1 GROSS VOLUME,GREEN WT
 2 .17572546E+01 .95480292E-01 .41994575E+01  42   MN1 GROSS VOLUME,GREEN WT
 3 .28715330E+10 .44371191E-04 .30966349E+01  36   MN1 GROSS VOLUME,GREEN WT
 4 .17447825E+04 .21916846E-02 .24072914E+01  35   MN1 GROSS VOLUME,GREEN WT
 5 .24917906E+06 .26315861E-03 .23977579E+01  45   MN1 GROSS VOLUME,GREEN WT
 6 .20596682E+07 .20108379E-03 .25821217E+01  32   MN1 GROSS VOLUME,GREEN WT
 7 .81119031E+00 .13064328E+00 .39933880E+01  47   MN1 GROSS VOLUME,GREEN WT
 8 .36057773E+06 .30379399E-03 .24863319E+01  28   MN1 GROSS VOLUME,GREEN WT
 9 .38799680E+04 .13200139E-02 .23002443E+01  43   MN1 GROSS VOLUME,GREEN WT
10 .38799680E+04 .13200139E-02 .23002443E+01  43   MN1 GROSS VOLUME,GREEN WT
11 .30247410E+06 .25658368E-03 .23960683E+01  49   MN1 GROSS VOLUME,GREEN WT
12 .61432027E+04 .10364514E-02 .23009816E+01  40   MN1 GROSS VOLUME,GREEN WT
13 .14251944E+07 .70003432E-04 .22194559E+01  48   MN1 GROSS VOLUME,GREEN WT
14 .14251944E+07 .70003432E-04 .22194559E+01  48   MN1 GROSS VOLUME,GREEN WT
15 .72758341E+05 .51094706E-03 .24996979E+01  54   MN1 GROSS VOLUME,GREEN WT
16 .19035053E+06 .20238435E-03 .22526878E+01  57   MN1 GROSS VOLUME,GREEN WT
17 .18967502E+04 .17450061E-02 .23015127E+01  43   MN1 GROSS VOLUME,GREEN WT
18 .18878049E+06 .20614364E-03 .22729089E+01  56   MN1 GROSS VOLUME,GREEN WT
19 .30247410E+06 .25658368E-03 .23960683E+01  49   MN1 GROSS VOLUME,GREEN WT
20 .61986968E+02 .13001896E-01 .28798039E+01  62   MN1 GROSS VOLUME,GREEN WT
21 .61986968E+02 .13001896E-01 .28798039E+01  62   MN1 GROSS VOLUME,GREEN WT
22 .61986968E+02 .13001896E-01 .28798039E+01  63   MN1 GROSS VOLUME,GREEN WT
23 .61986968E+02 .13001896E-01 .28798039E+01  63   MN1 GROSS VOLUME,GREEN WT
24 .56693257E+06 .30726635E-03 .26014555E+01  43   MN1 GROSS VOLUME,GREEN WT
25 .15095803E+06 .19377755E-03 .21840803E+01  43   MN1 GROSS VOLUME,GREEN WT
26 .22959612E+06 .21939416E-03 .23090850E+01  50   MN1 GROSS VOLUME,GREEN WT
27 .18878049E+06 .20614364E-03 .22729089E+01  52   MN1 GROSS VOLUME,GREEN WT
28 .18878049E+06 .20614364E-03 .22729089E+01  52   MN1 GROSS VOLUME,GREEN WT
29 .18878049E+06 .20614364E-03 .22729089E+01  52   MN1 GROSS VOLUME,GREEN WT
30 .18878049E+06 .20614364E-03 .22729089E+01  50   MN1 GROSS VOLUME,GREEN WT
31 .18878049E+06 .20614364E-03 .22729089E+01  50   MN1 GROSS VOLUME,GREEN WT
 1        .8677     .00854        1          MN1 SPECIES CORRECTION FACTORS
 2       1.0179    -.00550        2          MN1 SPECIES CORRECTION FACTORS
 3        .9588     .00000        3          MN1 SPECIES CORRECTION FACTORS
 4       1.0552     .00000        8          MN1 SPECIES CORRECTION FACTORS
 5        .9992     .00000       10          MN1 SPECIES CORRECTION FACTORS
 6        .9577     .00504        9          MN1 SPECIES CORRECTION FACTORS
 7       1.0552     .00000       12          MN1 SPECIES CORRECTION FACTORS
 8       1.0343     .00000       15          MN1 SPECIES CORRECTION FACTORS
 9        .8468     .00618       11          MN1 SPECIES CORRECTION FACTORS
10        .8677     .00854       17          MN1 SPECIES CORRECTION FACTORS
11        .9844     .00000       30          MN1 SPECIES CORRECTION FACTORS
12        .9739     .00000       33          MN1 SPECIES CORRECTION FACTORS
13       1.0219     .00000       28          MN1 SPECIES CORRECTION FACTORS
14       1.0219     .00000       28          MN1 SPECIES CORRECTION FACTORS
15        .9895     .00000       29          MN1 SPECIES CORRECTION FACTORS
16       1.0241     .00000       26          MN1 SPECIES CORRECTION FACTORS
17        .9707     .00000       24          MN1 SPECIES CORRECTION FACTORS
18       1.0442    -.00164       27          MN1 SPECIES CORRECTION FACTORS
19        .9611     .00000       31          MN1 SPECIES CORRECTION FACTORS
20        .9348     .00000       18          MN1 SPECIES CORRECTION FACTORS
21        .9658     .00191       20          MN1 SPECIES CORRECTION FACTORS
22        .9720     .00000       21          MN1 SPECIES CORRECTION FACTORS
23        .9611     .00000       22          MN1 SPECIES CORRECTION FACTORS
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24       .9151    .00365      37          MN1 SPECIES CORRECTION FACTORS
25       .9151    .00365      38          MN1 SPECIES CORRECTION FACTORS
26       .9821    .00205      39          MN1 SPECIES CORRECTION FACTORS
27      1.0000    .00000      49          MN1 SPECIES CORRECTION FACTORS
28      1.0000    .00000      49          MN1 SPECIES CORRECTION FACTORS
29      1.0000    .00000      49          MN1 SPECIES CORRECTION FACTORS
30      1.0000    .00000      49          MN1 SPECIES CORRECTION FACTORS
31      1.0000    .00000      49          MN1 SPECIES CORRECTION FACTORS
27          USE VOLUME EQUATIONS IN MINNESOTA FORM.  (SURVEY STATE CODE)
MINNESOTA UNIT 1            CUBIC FOOT VOLUME TREE CLASS 10
 5 1 1 1 2 3 2 3 3 1 1 4 5 4 4 4 4 4 4 4 4 4 4 5 5 4 4 4 4 4 4 MN1  CUFT TC10
MN1 CF10 1 .21540000E+04 .65100000E-02 .35200000E+01
MN1 CF10 2 .64000000E+02 .46000000E-02 .17800000E+01
MN1 CF10 3 .91524279E+00 .24112341E+00 .11451427E+02
MN1 CF10 4 .83000000E+02 .83000000E-02 .24400000E+01
MN1 CF10 5 .41768690E+03 .49219817E-02 .25899789E+01
                       MINN CUBIC FOOT VOLUME TREE CLASS 20
18 3 2 1 4 6 5 7 8 3 313141212181017111 13 9 9 9 9151610101010 9 9 MN1  CUFT TC20
MN1 CF20 1 .28972101E+10 .45372009E-04 .31282924E+01
MN1 CF20 2 .16650928E+01 .94595133E-01 .42292999E+01
MN1 CF20 3 .37466374E+04 .13285533E-02 .23137367E+01
MN1 CF20 4 .14214699E+04 .23318005E-02 .23822371E+01
MN1 CF20 5 .20358016E+07 .22634121E-03 .26126824E+01
MN1 CF20 6 .24216650E+06 .26201077E-03 .23979320E+01
MN1 CF20 7 .13038862E+01 .10502908E+00 .40625165E+01                MINN VOL.REG
MN1 CF20 8 .16644100E+01 .90925287E-01 .42919912E+01                MINN VOL.REG
MN1 CF20 9 .62323925E+02 .12621479E-01 .28786215E+01
MN1 CF2010 .18739563E+06 .21350158E-03 .22691608E+01
MN1 CF2011 .13664993E+06 .18888452E-03 .22073354E+01
MN1 CF2012 .79955838E+07 .14119657E-03 .27298454E+01
MN1 CF2013 .31223223E+06 .26318034E-03 .24369796E+01
MN1 CF2014 .56627231E+04 .10196967E-02 .23036378E+01
MN1 CF2015 .53277110E+06 .31430174E-03 .26321600E+01
MN1 CF2016 .16167180E+06 .20104843E-03 .22316894E+01
MN1 CF2017 .17900000E+04 .17000000E-02 .23000000E+01
MN1 CF2018 .69198214E+05 .51802127E-03 .25025657E+01
                       MINN CUBIC FOOT VOLUME TREE CLASS 30
11 1 1 1 2 3 2 4 5 1 1 910 8 811 711 6 9 6 6 6 61010 7 7 7 7 6 6 MN1  CUFT TC30
MN1 CF30 1 .21931159E+04 .13320763E-02 .22335697E+01
MN1 CF30 2 .52886471E+00 .14937753E+00 .46689976E+01
MN1 CF30 3 .67045745E+00 .89172270E-01 .30292410E+01
MN1 CF30 4 .79363099E+00 .97837980E-01 .29612688E+01
MN1 CF30 5 .81753981E+00 .12156620E+00 .52426035E+01
MN1 CF30 6 .92670312E+00 .11818976E+00 .58018115E+01
MN1 CF30 7 .69636778E+00 .13971019E+00 .56760170E+01
MN1 CF30 8 .78310170E+00 .12297015E+00 .57424357E+01
MN1 CF30 9 .16363869E+01 .10524914E+00 .60086471E+01
MN1 CF3010 .64074496E+00 .13404577E+00 .56018300E+01
MN1 CF3011 .61994648E+01 .66717450E-01 .68232202E+01
                       MINN CUBIC FOOT VOLUME TREE CLASS 40
10 1 1 1 1 2 1 2 3 1 1 7 8 6 610 510 4 7 4 4 4 4 8 8 9 9 9 9 4 4 MN1  CUFT TC40
MN1 CF40 1 .30840387E+01 .59396262E-01 .52999359E+01
MN1 CF40 2 .55904404E+00 .10190386E+00 .47594806E+01
MN1 CF40 3 .43863544E+00 .74168358E-01 .35210901E+01
MN1 CF40 4 .24577631E+01 .51382679E-01 .60114210E+01
MN1 CF40 5 .15022714E+00 .10573110E+00 .63126470E+01
MN1 CF40 6 .66596946E+01 .46796129E-01 .56145451E+01
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MN1 CF40 7 .78453306E-01 .19333277E+00 .40374400E+01
MN1 CF40 8 .49619658E+00 .35284779E-01 .17254951E+01
MN1 CF40 9 .16060590E+00 .17045254E+00 .58040220E+01
MN1 CF4010 .14447736E+00 .18230685E+00 .59406608E+01
                      MINN BOARD FOOT VOLUME TREE CLASS 10
 3 1 1 1 1 1 1 1 1 1 1 2 3 2 2 2 2 2 2 2 2 2 2 2 3 3 2 2 2 2 2 2 MN1  BDFT TC10
MN1 BF10 1 .36427960E+06 .87008589E-03 .26070406E+01
MN1 BF10 2 .20458717E+04 .33606172E-02 .22334050E+01
MN1 BF10 3 .20644432E+04 .33729791E-02 .22369948E+01
                      MINN BOARD FOOT VOLUME TREE CLASS 20
14 3 2 1 4 6 5 6 7 3 31011 8 814 913 810 8 8 8 81212 9 9 9 9 8 8 MN1  BDFT TC20
MN1 BF20 1 .88726721E+05 .13006471E-02 .26171044E+01
MN1 BF20 2 .16140745E+05 .54154500E-03 .18000427E+01
MN1 BF20 3 .50184080E+04 .26130193E-02 .23950691E+01
MN1 BF20 4 .23792600E+07 .60450931E-03 .29556387E+01
MN1 BF20 5 .35444785E+07 .68911048E-03 .30314328E+01
MN1 BF20 6 .39887217E+04 .23251087E-02 .22640536E+01
MN1 BF20 7 .38687357E+04 .25149610E-02 .22101820E+01
MN1 BF20 8 .21802550E+05 .37437360E-03 .17986225E+01
MN1 BF20 9 .73284722E+04 .50627685E-03 .16759540E+01
MN1 BF2010 .89076809E+04 .48432326E-03 .16519990E+01
MN1 BF2011 .40588173E+06 .18875960E-03 .20828578E+01
MN1 BF2012 .93223489E+03 .56563295E-02 .24324702E+01
MN1 BF2013 .77913387E+03 .54791695E-02 .23529415E+01
MN1 BF2014 .10066441E+06 .11001271E-02 .26283184E+01
                      MINN BOARD FOOT VOLUME TREE CLASS 31
 4 1 1 1 1 1 1 1 2 1 1 3 4 3 3 3 3 3 3 3 3 3 3 3 4 4 3 3 3 3 3 3 MN1  BDFT TC31
MN1 BF31 1 .55017844E+01 .10167611E+00 .49336766E+01
MN1 BF31 2 .24448081E+01 .62316562E-01 .17087329E+01
MN1 BF31 3 .18463914E+02 .57351004E-01 .50173406E+01
MN1 BF31 4 .29633584E+06 .14492967E-03 .20614655E+01
             MINN CUBIC FOOT VOLUME IN SAWLOG PORTION TREE CLASS 10
 3 1 1 1 1 1 1 1 1 1 1 2 3 2 2 2 2 2 2 2 2 2 2 2 3 3 2 2 2 2 2 2 MN1  CFSL TC10
MN1 CL10 1 .10562000E+05 .14800000E-02 .25260000E+01
MN1 CL10 2 .21998941E+04 .15836863E-02 .23061826E+01
MN1 CL10 3 .30489834E+04 .18488399E-02 .24854923E+01
             MINN CUBIC FOOT VOLUME IN SAWLOG PORTION TREE CLASS 20
14 3 2 1 4 6 5 6 7 3 31011 8 814 913 810 8 8 8 81212 9 9 9 9 8 8 MN1  CFSL TC20
MN1 CL20 1 .34724823E+04 .19132744E-02 .25001269E+01
MN1 CL20 2 .42552718E+04 .27879516E-03 .16634241E+01
MN1 CL20 3 .22750000E+04 .17000000E-02 .23800000E+01
MN1 CL20 4 .16498026E+04 .64100142E-03 .17784872E+01
MN1 CL20 5 .16630000E+04 .14900000E-02 .21350000E+01
MN1 CL20 6 .17555205E+04 .14654734E-02 .22451216E+01
MN1 CL20 7 .15206155E+04 .14063529E-02 .20991661E+01
MN1 CL20 8 .50961639E+04 .14511642E-03 .16002125E+01
MN1 CL20 9 .11868819E+04 .13317865E-03 .13228810E+01
MN1 CL2010 .24572107E+04 .18872370E-03 .14823480E+01
MN1 CL2011 .15842509E+04 .14787729E-03 .14008905E+01
MN1 CL2012 .31853919E+03 .30318397E-02 .21989733E+01
MN1 CL2013 .26289575E+03 .28374129E-02 .20958490E+01
MN1 CL2014 .34348377E+05 .54079890E-03 .24003267E+01
             MINN CUBIC FOOT VOLUME IN SAWLOG PORTION TREE CLASS 31
 4 1 1 1 1 1 1 1 2 1 1 3 4 3 3 3 3 3 3 3 3 3 3 3 4 4 3 3 3 3 3 3 MN1  CFSL TC31
MN1 CL31 1 .61065394E+03 .19432680E-02 .22056695E+01
MN1 CL31 2 .10711490E+03 .14631036E-02 .15869698E+01
MN1 CL31 3 .44558664E+03 .22802744E-02 .22705239E+01
MN1 CL31 4 .57949571E+02 .91595682E-03 .13250221E+01
```

APPENDIX III.

TGPS System Parameters and Specifications

```
**********************************************************************
*                                                                    *
*   LISTING OF SYSTEM PARAMETER INPUT FILE FREP-R9*STEMS.SYSINPFXX   *
*   FOR TGPS. ALL LINES THAT BEGIN WITH AN ASTERISK (*) ARE FOR      *
*   DISCUSSION PURPOSES ONLY AND DO NOT APPEAR IN THE ACTUAL         *
*   DATA FILE.                                                       *
*                                                                    *
**********************************************************************
*
*
*
**********************************************************************
*     SPECIES GROUP CONVERSION SECTION.                              *
**********************************************************************
*
NUMBER SPECIES GROUPS = 31 CODE OTHER SOFTWOODS = 10 CODE OTHER HARDWOODS = 30
NUMBER LAST SOFTWOOD = 299 NUMBER OF LAST HARDWOOD = 999
 105  1             JACK PINE           JACK PINE
 125  2             RED PINE            RED PINE
 129  3             WHITE PINE          WHITE PINE
 012  5             BALSAM FIR          BALSAM FIR
  94  4             WHITE SPRUCE        WH. SPRUCE
  95  6             BLACK SPRUCE        BLK.SPRUCE
  71  7             TAMARACK            TAMARACK
 241  8             NORTH.WHITE CEDAR   N.WH.CEDAR
 261  9             HEMLOCK             HEMLOCK
 130  1             SCOTCH PINE         JACK PINE
 543 11             BLACK ASH           BLK.GR.ASH
 544 11             GREEN ASH           BLK.GR.ASH
 742 12             COTTONWOOD          COTTONWOOD
 317 13             SILVER MAPLE        SIL.MAPLE
 316 14             RED MAPLE           RED MAPLE
 972 15             ELM,AMERICAN        ELM
 974 15             ELM                 ELM
 975 15             ELM,RED             ELM
 977 15             ELM,ROCK            ELM
 371 16             YELLOW BIRCH        YEL.BIRCH
 951 17             BASSWOOD            BASSWOOD
 318 18             SUGAR MAPLE         HARD MAPLE
 314 18             BLACK MAPLE         HARD MAPLE
 541 19             WHITE ASH           WHITE ASH
 802 20             WHITE OAK           WHITE OAK
 804 20                                 WHITE OAK
 823 20                                 WHITE OAK
 826 20                                 WHITE OAK
 832 20                                 WHITE OAK
 833 21                                 S.RED OAK
 834 21                                 S.RED OAK
 806 22                                 O.RED OAK
 809 22                                 O.RED OAK
 830 22                                  O.RED OAK
 837 22                                  O.RED OAK
 402 23                                  HICKORY
 403 23                                  HICKORY
 405 23                                  HICKORY
 407 23                                  HICKORY
 409 23                                  HICKORY
 743 24             BIGTOOTH ASPEN       B.T.ASPEN
 741 25             BALSAM POPLAR        QUAK.ASPEN
 746 25             QUAKING ASPEN        QUAK.ASPEN
 375 26             PAPER BIRCH          PAP.BIRCH
 999 31                                  NONCOMMER.
*
************************************************************************
*     CROWN RATIO FUNCTION COEFFICIENTS.                               *
************************************************************************
*
CR.PAR  01    .66400E+01    .01350E+00    .32000E+01   -.05180E+00
CR.PAR  02    .53500E+01    .00530E+00    .15280E+01   -.03300E+00
CR.PAR  03    .67900E+01    .00580E+00    .75900E+01   -.01030E+00
CR.PAR  04    .78400E+01    .00570E+00    .12720E+01   -.14200E+00
CR.PAR  05    .56300E+01    .00470E+00    .35230E+01   -.06890E+00
CR.PAR  06    .55400E+01    .00720E+00    .42000E+01   -.05300E+00
CR.PAR  07    .60000E+01    .00530E+00    .43100E+00   -.00120E+00
CR.PAR  08    .57100E+01    .00770E+00    .22900E+01   -.25300E+00
CR.PAR  09    .57100E+01    .00770E+00    .22900E+01   -.25300E+00
CR.PAR  10    .57100E+01    .00770E+00    .22900E+01   -.25300E+00
CR.PAR  11    .45000E+01    .00320E+00    .79500E+01   -.10500E+00
CR.PAR  12    .43500E+01    .00460E+00    .18200E+01   -.27400E+00
CR.PAR  13    .48500E+01    .00500E+00    .98100E+01   -.00990E+00
CR.PAR  14    .43500E+01    .00460E+00    .18200E+01   -.27400E+00
CR.PAR  15    .44000E+01    .00250E+00    .10000E+01   -.09400E+00
CR.PAR  16    .41800E+01    .00250E+00    .14100E+01   -.51200E+00
CR.PAR  17    .44400E+01    .00370E+00    .20900E+01   -.06500E+00
CR.PAR  18    .34000E+01    .00660E+00    .28700E+01   -.43400E+00
CR.PAR  19    .44900E+01    .00290E+00    .12100E+01   -.06500E+00
CR.PAR  20    .58400E+01    .00820E+00    .32600E+01   -.04900E+00
CR.PAR  21    .42000E+01    .00160E+00    .27600E+01   -.02500E+00
CR.PAR  22    .50600E+01    .00330E+00    .17300E+01   -.06100E+00
CR.PAR  23    .62100E+01    .00730E+00    .99900E+01   -.01000E+00
CR.PAR  24    .41100E+01    .00540E+00    .16500E+01   -.11000E+00
CR.PAR  25    .40000E+01    .00240E+00   -.28300E+01    .02100E+00
CR.PAR  26    .50000E+01    .00660E+00    .49200E+01   -.02630E+00
CR.PAR  27    .40000E+01    .00240E+00   -.28300E+01    .02100E+00
CR.PAR  28    .40000E+01    .00240E+00   -.28300E+01    .02100E+00
CR.PAR  29    .40000E+01    .00240E+00   -.28300E+01    .02100E+00
CR.PAR  30    .40000E+01    .00240E+00   -.28300E+01    .02100E+00
CR.PAR  31    .40000E+01    .00240E+00   -.28300E+01    .02100E+00
```

```
*
**********************************************************************
*     COVER TYPE NAMES AND MANAGEMENT GUIDE ASSIGNMENTS.             *
**********************************************************************
*
  01   01 JACK PINE         02   02 RED PINE          03   03 WHITE PINE
  05   11 HEMLOCK           11   04 BALSAM FIR        12   05 BLACK SPRUCE
  14   07 N. WHITE-CEDAR    15   05 TAMARACK          16   04 WHITE SPRUCE
  18   06 MIX. SWAMP CONF.  40   08 OAK-PINE          53   08 W.OAK-R.OAK-HIC.
  54   08 WHITE OAK         55   08 N. RED OAK        71   12 B.ASH-ELM-MAPLE
  73   12 COTTONWOOD        81   11 MAPLE-BEECH-BIR.  91   09 ASPEN
  92   10 PAPER BIRCH       96   14 OTHER SOFTWOODS   97   14 OTHER HARDWOODS
  98   14 NON-COMMERCIAL    99   14 NON-STOCKED       00   14 TYPE MISMATCH
*
**********************************************************************
*     CRITICAL VALUES FOR MANAGEMENT GUIDES.                         *
**********************************************************************
*
JP SCREEN PARA.    .5   400  2000    60    40    70    60   140   120    80
JP SCREEN PARA. .6667 68.89  1141  40.4
RP SCREEN PARA.    .5   400     2     9    15    20  2000   160   160   140
RP SCREEN PARA.   120   140   180   200    90    .5   120    .5   150 86.40
RP SCREEN PARA.  1328 85.86
WP SCREEN PARA.    .5   400    20    40   120   110   110   110   110    60
WP SCREEN PARA.    70    70    70    70  40.0
SF SCREEN PARA.    .5   400    40    50    35    20    40   100    45    35
SF SCREEN PARA.   140    75   100    65
BS SCREEN PARA.    25 209.0 1837. 10.60   80.-175.4 2.583
SC SCREEN PARA.    25    36   120    50    60    80    90   100    50    60
SC SCREEN PARA.    80    60    60
WC SCREEN PARA.    25    36   120    50    60   150    50    60   130   200
WC SCREEN PARA.   200   150    60   150    60
OK SCREEN PARA.    55    75    60   100    60    80    50    70    .5    .5
OK SCREEN PARA.    .5    10    10    10    16    20    24    10    25    10
OK SCREEN PARA.    25    10    25    15    15    15  58.0
AS SCREEN PARA.    56    70    20    30    45    20    30    55  2000  1000
AS SCREEN PARA.   130    65  5.56   1.4 -.383
PB SCREEN PARA.    .5    50    60    40    50    80    65   120    80    65
NH SCREEN PARA.    .7  1000    80   9.6    20    16    20    70   110    75
NH SCREEN PARA.   160    90    80    80    85   120    70    70    70    15
LH SCREEN PARA.    55    90    90   100   110    85    85    75
US SCREEN PARA.    20    10
```

```
*
**********************************************************************
*     MORTALITY EQUATION ASSIGNMENTS AND COEFFICIENTS.              *
**********************************************************************
*
25 1 2 3 4 5 6 7 8 9 2101111111213141516171819202122232424242425
MORT JP   1 -.0660000E+00  .6879000E+02  .9780000E+00  .0023000E+00  .000000E+00
MORT RP   2  .1084300E+01  .1101200E+02  .5886600E+00  .0002000E+00  .485000E+00
MORT WP   3  .2350700E+01  .3360900E+02  .1008800E+01  .0020100E+00  .000000E+00
MORT WS   4  .2880600E+01  .3077400E+02  .1230900E+01  .0039600E+00  .000000E+00
MORT BF   5  .2697600E+01  .3055000E+02  .8996300E+00  .0040000E+00 -.230690E+00
MORT BS   6  .2877400E+01  .4329500E+03  .1857600E+01  .0023500E+00  .000000E+00
MORT TAM 7   .0246000E+00  .1607000E+03  .1000000E+01  .0210000E+00  .000000E+00
MORT NWC 8   .2877400E+01  .4329500E+03  .1857600E+01  .0023500E+00  .000000E+00
MORT HEM 9   .2910000E+01  .4080000E+03  .1640000E+01  .0015000E+00  .000000E+00
MORT BA 10   .1640000E+01  .9146000E+02  .1000000E+01  .0094000E+00  .000000E+00
MORT RM 11   .3050000E+01  .3825000E+02  .1000000E+01  .0022000E+00  .000000E+00
MORT ELM12   .2450000E+01  .4080000E+02  .1000000E+01  .0042000E+00  .000000E+00
MORT YB 13   .2340000E+01  .1485000E+03  .1400000E+01  .0032000E+00  .000000E+00
MORT BW 14   .2420000E+01  .5604000E+02  .1000000E+01  .0035000E+00  .000000E+00
MORT HM 15   .8150000E+00  .6693700E+02  .1593400E+01  .0043500E+00  .750000E+00
MORT WA 16   .1782100E+01  .2323100E+03  .1726700E+01  .0022200E+00  .000000E+00
MORT WO 17   .3170000E+01  .2356000E+02  .8000000E+00  .0014000E+00  .000000E+00
MORT SR018   .2309200E+01  .6999800E+04  .2661500E+01  .0046800E+00  .000000E+00
MORT OR019   .2309200E+01  .6999800E+04  .2661500E+01  .0046800E+00  .000000E+00
MORT HI 20   .3062600E+01  .6349500E+02  .1049800E+01  .0013400E+00  .000000E+00
MORT BTA21   .8805000E+00  .5659300E+02  .1215400E+01  .0128800E+00  .000000E+00
MORT QA 22  -.5600000E+00  .2530000E+02  .6800000E+00  .0190000E+00  .000000E+00
MORT PB 23   .2160000E+01  .2880000E+02  .1000000E+01  .0000000E+00  .000000E+00
MORT OHD24   .2233900E+01  .2962900E+02  .1342700E+01  .0074800E+00  .000000E+00
MORT NON25   .2380000E+01  .8590000E+02  .1000000E+01  .0169000E+00  .000000E+00
*
************************************************************************
*     POTENTIAL DIAMETER GROWTH EQUATION ASSIGNMENTS AND COEFFICIENTS. *
************************************************************************
*
24 1 2 3 4 5 6 7 8 9 1101111111213141516171819202122232424242424 GROW.ASSIGN
GROW JP   1  .1606200E-00 -.9000000E-05  .3624500E+01  .4000000E-04  .100000E+01
GROW RP   2  .9446000E-01 -.1200000E-03  .2059600E+01  .3500000E-03  .242250E+00
GROW WP   3  .2557800E-00 -.8800000E-03  .1726300E+01  .4000000E-04  .100000E+01
GROW WS   4  .1705600E-00 -.1451600E-01  .1066000E+01  .5200000E-03  .272980E+00
GROW BF   5  .1220000E-00 -.8000000E-03  .1989000E+01  .6000000E-04  .100000E+01
GROW BS   6  .1071300E+00 -.1070000E-02  .2001700E+01  .6000000E-04  .911270E+00
GROW  T   7  .1114700E-00 -.1000000E-04  .3068500E+01  .3000000E-04  .100000E+01
GROW WC   8  .1340300E-00 -.1000000E-05  .3688000E+01  .2000000E-04  .100000E+01
GROW HE   9  .1687200E-00 -.3000000E-06  .3573800E+01  .1000000E-04  .100000E+01
GROW BA 10   .5880700E-01 -.6000000E-08  .5055900E+01  .2400000E-03  .315530E-00
GROW RM 11   .1094800E-00 -.4000000E-04  .2222600E+01  .5000000E-03  .662600E-01
GROW ELM12   .2849600E-00 -.1820000E-02  .1529700E+01  .3000000E-04  .100000E+01
GROW YB 13   .1515500E-00 -.3000000E-05  .3310400E+01  .7000000E-04  .573020E+00
GROW BAS14   .2540200E-00 -.4000000E-05  .2939600E+01  .1000000E-04  .100000E+01
GROW HM 15  .1877200E-00 -.7000000E-05  .2583900E+01  .2800000E-03  .838500E-01
GROW WA 16  .2116700E-00 -.3000000E-05  .3313100E+01  .1000000E-04  .124300E+00
GROW WO 17  .1265400E-00 -.4000000E-05  .2753800E+01  .5000000E-04  .620860E+00
GROW SR018  .1553500E-00 -.1000000E-06  .3536700E+01  .1800000E-03  .259000E-00
GROW OR019  .1735800E-00 -.7000000E-04  .2445100E+01  .3000000E-04  .952220E-00
GROW HI 20  .1647100E-00 -.2161000E-02  .1394900E+01  .4000000E-04  .716280E-00
GROW BTA21  .2349000E-00 -.9420000E-02  .1104100E+01  .3600000E-03  .153860E-00
GROW QA 22  .2164500E-00 -.9100000E-04  .2603000E+01  .4400000E-04  .100000E+01
GROW PB 23  .1097100E-00 -.3200000E-03  .2023600E+01  .3400000E-03  .212880E-00
GROW OH 24  .3751000E-00 -.2479000E-01  .9628800E+00  .4000000E-04  .100000E+01
*
************************************************************************
*     MODIFIER FUNCTION COEFFICIENTS.                                  *
************************************************************************
*
MOD   1   1.0000E+00   .2250E+03   .5710E+01   -.9260E+00   .3810E+01   .165E+00
MOD   2N  1.0000E+00   .3000E+03   .1350E+01   -.2230E+01   .2640E+01   .000E+00
MOD   3   1.0000E+00   .3000E+03   .1530E+01   -.2130E+01   .5880E+01   .274E+00
MOD   4   1.0000E+00   .3500E+03   .7670E+01   -.9390E+00   .4700E+01   .254E+00
MOD   5   1.0000E+00   .3250E+03   .1650E+01   -.1940E+01   .8950E+01   .589E+00
MOD   6   1.0000E+00   .2750E+03   .2500E+01   -.1600E+01   .8350E+01   .620E+00
MOD   7   1.0000E+00   .2000E+03   .5290E+00   -.2200E+01   .3230E+01   .638E+00
MOD   8    .9000E+00   .3500E+03   .2000E+01   -.1570E+01   .3510E+01   .120E+00
MOD   9   1.0000E+00   .3000E+03   .9320E+00   -.1580E+01   .4780E+01   .690E+00
MOD  10   1.0000E+00   .3000E+03   .1530E+01   -.2130E+01   .5880E+01   .274E+00
MOD  11   1.0000E+00   .2500E+03   .6230E+00   -.3390E+01   .2990E+02   .777E+00
MOD  12   1.0000E+00   .2500E+03   .1430E+01   -.2340E+01   .1280E+02   .610E+00
MOD  13   1.0000E+00   .2500E+03   .1430E+01   -.2340E+01   .1280E+02   .610E+00
MOD  14   1.0000E+00   .2500E+03   .1430E+01   -.2340E+01   .1280E+02   .610E+00
MOD  15   1.2000E+00   .2500E+03   .1050E+02   -.3070E+00   .1980E+01   .247E+00
MOD  16   1.0000E+00   .2500E+03   .7360E+00   -.6790E+01   .5350E+02   .307E+00
MOD  17   1.3000E+00   .2500E+03   .2860E+01   -.1080E+01   .3240E+01   .253E+00
MOD  18   1.0000E+00   .2500E+03   .1000E+01   -.3330E+01   .1040E+02   .315E+00
MOD  19   1.6000E+00   .2500E+03   .1170E+02   -.4500E+00   .2670E+01   .219E+00
MOD  20   1.0000E+00   .2500E+03   .8170E+00   -.3450E+01   .1530E+02   .501E+00
MOD  21   1.0000E+00   .2500E+03   .1530E+01   -.1500E+01   .4600E+01   .520E+00
MOD  22   1.0000E+00   .2500E+03   .1530E+01   -.1500E+01   .4600E+01   .520E+00
MOD  23   1.0000E+00   .2500E+03   .3020E+01   -.1100E+01   .3540E+01   .280E+00
MOD  24   1.0000E+00   .3000E+03   .1080E+01   -.4810E+01   .4410E+02   .245E+00
MOD  25   1.0000E+00   .3000E+03   .1140E+01   -.4660E+01   .5250E+02   .307E+00
MOD  26   1.0000E+00   .3000E+03   .1260E+01   -.2600E+01   .8560E+01   .350E+00
MOD2P27   1.0000E+00   .3500E+03   .2890E+01   -.1300E+01   .3330E+01   .000E+00
MOD  28   1.0000E+00   .2500E+03   .1530E+01   -.1500E+01   .4600E+01   .520E+00
MOD  29   1.0000E+00   .2500E+03   .1530E+01   -.1500E+01   .4600E+01   .520E+00
MOD  30   1.0000E+00   .2500E+03   .1530E+01   -.1500E+01   .4600E+01   .520E+00
MOD  31   1.0000E+00   .2500E+03   .1530E+01   -.1500E+01   .4600E+01   .520E+00
MOD   1    .4040E+00   .4860E+00   .4950E+04   .4000E+00                    .000E+00
MOD   2N   .1070E-02   .4260E+01   .1030E+02   .6000E+00                    .000E+00
MOD   3    .2610E-02   .3290E+01   .2410E+02   .4000E+00                    .000E+00
MOD   4    .0000E+00   .1000E+01   .1000E+01   .7700E+00                    .000E+00
MOD   5    .1290E+00   .2310E+01   .4000E+01   .5000E+00                    .000E+00
MOD   6    .3090E+00   .2020E+01   .4350E+01   .3000E+00                    .000E+00
MOD   7    .1230E-03   .4460E+01   .1400E+02   .2000E+00                    .000E+00
MOD   8    .0000E+00   .1000E+01   .1000E+01   .8700E+00                    .000E+00
MOD   9    .4260E-04   .4170E+01   .2490E+02   .3500E+00                    .000E+00
MOD  10    .2610E-02   .3290E+01   .2410E+02   .4000E+00                    .000E+00
MOD  11    .4590E-02   .3190E+01   .9600E+01   .4000E+00                    .000E+00
MOD  12    .2490E-01   .1940E+01   .3520E+02   .5000E+00                    .000E+00
MOD  13    .2490E-01   .1940E+01   .3520E+02   .5000E+00                    .000E+00
MOD  14    .2490E-01   .1940E+01   .3520E+02   .5000E+00                    .000E+00
MOD  15    .2150E-02   .2660E+01   .4170E+02   .3000E+00                    .000E+00
MOD  16    .4120E-01   .2360E+01   .1310E+02   .2000E+00                    .000E+00
MOD  17    .7250E-02   .2560E+01   .1200E+02   .3000E+00                    .000E+00
MOD  18    .3110E-01   .2140E+01   .1620E+02   .4000E+00                    .000E+00
MOD  19    .0000E+00   .1000E+01   .1000E+01   .4700E+00                    .000E+00
MOD  20    .1430E-02   .3450E+01   .2110E+02   .2000E+00                    .000E+00
MOD  21    .2020E-02   .3070E+01   .2110E+02   .5000E+00                    .000E+00
MOD  22    .2020E-02   .3070E+01   .2110E+02   .5000E+00                    .000E+00
MOD  23    .6230E-02   .2800E+01   .2150E+02   .4000E+00                    .000E+00
MOD  24    .9420E-03   .3480E+01   .1940E+02   .6000E+00                    .000E+00
MOD  25    .7650E-02   .2890E+01   .2040E+02   .3000E+00                    .000E+00
MOD  26    .3530E-03   .4200E+01   .9650E+01   .5000E+00                    .000E+00
MOD2P27    .3760E-03   .3560E+01   .2820E+02   .6000E+00                    .000E+00
MOD  28    .2020E-02   .3070E+01   .2110E+02   .5000E+00                    .000E+00
MOD  29    .2020E-02   .3070E+01   .2110E+02   .5000E+00                    .000E+00
MOD  30    .2020E-02   .3070E+01   .2110E+02   .5000E+00                    .000E+00
MOD  31    .2020E-02   .3070E+01   .2110E+02   .5000E+00                    .000E+00
*
*************************************************************************
*     MARKING GUIDE FOR MANAGEMENT ROUTINES.                            *
*************************************************************************
*
JP 1    8100000000000              0              0              0              0
JP 2    8100000000000  7100000000000              0              0              0
JP 3    1009900000000  2009901020304 -4009901020304              0              0
RP 1   -2009901020304  8120000000000              0              0              0
RP 2   -2009901020304  8120000000000  7100000000000              0              0
RP 3    7100000000000              0              0              0              0
RP 4    1009900000000  2009902000000 -4009902000000              0              0
RP 5    1009900000000  2009902000000 -4009902000000              0              0
RP 6    1009900000000  2009902000000 -4009902000000              0              0
WP 1   -2009902030400  8120000000000              0              0              0
WP 2    5069901242500  1009900000000  2009902030400 -4009902030400              0
WP 3    5069901242500  1009900000000  2009902030400 -4009902030400              0
WP 4    5059905000000  1009900000000  2009902030400 -4009902030400              0
WP 5    5069901242500  1009900000000  2009902030400 -4009902030400              0
WP 6  1009900000000  6009903000000              0              0              0
SF 1  9009924250000              0              0              0              0
SF 2 -2009904000000  8120000000000              0              0              0
SF 3  1009900000000  3009904000000 -4009904000000              0              0
SF 4  1009900000000  3009904000000 -4009904000000              0              0
SC 1  9069924250000  9059905000000              0              0              0
SC 2  9009915242526  9009911141600              0              0              0
SC 3  1009900000000  6009904060708              0              0              0
SC 4  9059905000000  9009915242526  9009911141600              0              0
SC 5  1009900000000  6009904060708              0              0              0
WC 1  9069924250000  9059905000000              0              0              0
WC 2  1009900000000  2009904060800 -4009904060800              0              0
WC 3  1009900000000  6009904060800              0              0              0
WC 4  9069924250000  9059905000000              0              0              0
WC 5  1009900000000  2009904060800 -4009904060800              0              0
WC 6  1009900000000  6009904060800              0              0              0
OK 1  1009900000000  2009901020300 -4009901020300              0              0
OK 2  1009900000000  2009901020300 -4009901020300              0              0
OK 3  1009900000000  2009901020300 -4009901020300              0              0
OK 4  1009900000000  2009920212223 -4009920212223              0              0
OK 5  1009900000000  2009920212223 -4009920212223              0              0
OK 6  1009900000000  2009920212223 -4009920212223              0              0
OK 7  1009900000000  2009917181900 -4009917181900              0              0
OK 8  1009900000000  2009917181900 -4009917181900              0              0
OK 9  1009900000000  2009917181900 -4009917181900              0              0
AS 1  1009900000000  3009924250000 -4009924250000              0              0
PB 1  1009900000000  2009924252600 -4009924252600              0              0
PB 2  1009900000000  6009926000000              0              0              0
NH 1  8080000000000              0              0              0              0
NH 2  1009900000000  5109915000000 -5009918000000 -2009916171921 -4009916171921
NH 3  1009900000000  5109915000000 -5009918000000 -2009916171921 -4009916171921
NH 4  1009900000000  6009916171921              0              0              0
NH 5  1009900000000  5109915000000 -2009909160000 -4009909160000              0
NH 6  1009900000000  6009909160000              0              0              0
NH 7  1109900000000 -3189916171800 -5229916171800 -2109916171800 -4109916171800
NH 8  1051000000000              0              0              0              0
NH 9  1999900000000              0              0              0              0
NH10  1051000000000 -2051016171800 -4051016171800              0              0
NH11  1109900000000 -3189916171800 -5229916171800 -2109916171800 -4109916171800
NH12  1051000000000 -2051016171800 -4051016171800              0              0
LH 1  1009900000000  5009915000000 -2009911141600 -4009911141600              0
LH 2  1009900000000  5009915000000 -2009911141600 -4009911141600              0
LH 3  1009900000000  5009915000000  6009911141600              0              0
*
************************************************************************
*     SPECIES SITE INDEX CONVERSION COEFFICIENTS.                      *
************************************************************************
*
 2 1 23.850 .630 1 2 19.380 .640 3 2 18.840 .680 4 2 26.580 .560 2 3 15.900 .690
 4 3 20.060 .600 2 4-11.8701.170 3 4 -1.3001.030 8 5 24.470 .92011 5 18.690 .810
 7 6 11.560 .540 6 7  7.480 .950 5 8  4.870 .470 511   7.040 .6501114  5.616 .870
1115 13.004 .8041116 22.082 .5851117 13.427 .7971118  7.706 .8011119  3.969 .981
1122 35.708 .4441411 20.283 .6881415  8.686 .8991416 10.943 .8021417  9.417 .892
1418  3.336 .9301419   .0171.0651422 18.470 .7601424 21.133 .7661425 21.133 .766
1426 21.976 .6751511 11.452 .8141514 19.926 .6281516 11.861 .7461517 14.611 .770
1518 10.609 .7661519  4.696 .9631522 35.862 .4291524  6.5931.0111525 6.5931 .011
1526 14.042 .7841611  1.6281.0491614  7.837 .8761615  1.3711.0501617 11.951 .880
1618  6.787 .8851619  9.273 .9561622 14.390 .8671624 12.670 .9581625 12.670 .958
1626 17.342 .8061711 13.243 .7891714  4.068 .8811715  6.421 .9041716  2.585 .883
1718  6.299 .8321719   .8851.0121724 17.712 .8471725 17.712 .8471726 13.238 .813
1811 20.285 .7431814  9.362 .8511815  8.840 .9251816 10.327 .8251817 15.101 .821
1819 10.572 .9411822 35.432 .4931824 25.430 .7761825 25.430 .7761826 21.018 .726
1911 12.862 .7661914 21.977 .5931915 10.769 .8071916 12.318 .7151917 18.977 .689
1918 11.189 .7281922 27.478 .5661924 23.089 .7671925 23.089 .7671926 21.765 .674
2621 10.430 .7602211 -9.9461.1542214 -1.339 .9512215  7.671 .9032216  3.045 .849
2218   .906 .8852219-22.9331.3622224 13.919 .8832225 13.919 .8832226 23.734 .628
2416 -5.865 .9342417  1.483 .8552418  2.624 .7802419-17.0001.1112422 15.208 .672
2426  5.271 .8492515  5.206 .8162516 -5.865 .9342517  1.483 .8552518  2.624 .780
2519-17.0001.1112522 15.208 .6722526  5.271 .8492614 -3.591 .9992615  5.168 .899
2616  -.765 .9032617  9.115 .8252618  6.306 .8092619 -3.8531.0232126 29.010 .580
2622   .014 .9972624  -.2391.0772625  -.2391.077
99
*
**********************************************************************
*     CRITICAL VALUES FOR REGENERATION ROUTINES.                     *
**********************************************************************
*
JP 1 1 2 1 1 1  4 1000 1.5 0.10
JP 1 2 2 1 1 1  2  800 1.5 0.10
JP 1 3 2 1 1 1  1  900 1.5 0.10
RP 2 1 2 1 1 1  2  800 1.5 0.10
WP 3 1 2 1 1 1  2  800 1.5 0.10
WP 3 2 1 1 1 1  3 1000 1.5 0.10
SF 4 1 1 1 1 2  5  800 2.0 0.15  4  400 1.0 0.05
SF 4 2 2 1 1 1  4 1000 2.0 0.15
SF 4 3 1 1 0 2 25  800 1.8 0.10  5  400 1.0 0.08
SF 4 4 2 1 1 1  4 1000 2.0 0.20
SF 4 5 1 1 0 2 25  800 1.8 0.10  5  400 1.0 0.05
SF 4 6 2 1 1 1  4 1000 1.8 0.15
SF 4 7 2 1 1 1  4 1000 2.0 0.05
BS 5 1 1 1 1 1  6 1000 1.5 0.05
BS 5 2 1 1 0 1  6 1200 2.0 0.15
MC 6 1 1 1 1 5  4  240 1.5 0.15  5  240 1.4 0.05  6  240 1.3 0.05
                7  240 1.2 0.05  8  240 1.1 0.05
NC 7 1 1 0 0 1  8 1000 2.0 0.10
NC 7 2 1 1 1 1  8 1200 2.5 0.15
AS 9 1 2 1 1 1  4 1000 1.5 0.10
AS 9 2 2 1 1 1  2  800 1.5 0.10
AS 9 3 2 1 1 1  1  900 1.5 0.10
AS 9 4 1 1 0 1 25 1200 1.0 0.05
AS 9 5 2 1 1 1  4 1000 1.5 0.10
AS 9 6 2 1 1 1  2  800 1.5 0.10
AS 9 7 2 1 1 1  1  900 1.5 0.10
AS 9 8 2 1 1 1  4 1000 1.5 0.10
AS 9 9 2 1 1 1  2  800 1.5 0.10
AS 910 2 1 1 1  1  900 1.5 0.10
PB10 1 1 1 0 1 26 1000 1.0 0.10
PB10 2 2 1 1 1  2  800 1.8 0.15
PB10 3 2 1 1 1  1  900 1.9 0.19
```

```
*
*********************************************************************
*     HEIGHT FUNCTION COEFFICIENTS. THESE COEFFICIENTS              *
*     WILL BE REPLACED BY ACTUAL DATA DECK WHEN AVAILABLE.          *
*********************************************************************
*
 HTVAL 01 0000000000 0000000000 0000000000 0000000000
 HTVAL 02 0000000000 0000000000 0000000000 0000000000
 HTVAL 03 0000000000 0000000000 0000000000 0000000000
 HTVAL 04 0000000000 0000000000 0000000000 0000000000
 HTVAL 05 0000000000 0000000000 0000000000 0000000000
 HTVAL 06 0000000000 0000000000 0000000000 0000000000
 HTVAL 07 0000000000 0000000000 0000000000 0000000000
 HTVAL 08 0000000000 0000000000 0000000000 0000000000
 HTVAL 09 0000000000 0000000000 0000000000 0000000000
 HTVAL 10 0000000000 0000000000 0000000000 0000000000
 HTVAL 11 0000000000 0000000000 0000000000 0000000000
 HTVAL 12 0000000000 0000000000 0000000000 0000000000
 HTVAL 13 0000000000 0000000000 0000000000 0000000000
 HTVAL 14 0000000000 0000000000 0000000000 0000000000
 HTVAL 15 0000000000 0000000000 0000000000 0000000000
 HTVAL 16 0000000000 0000000000 0000000000 0000000000
 HTVAL 17 0000000000 0000000000 0000000000 0000000000
 HTVAL 18 0000000000 0000000000 0000000000 0000000000
 HTVAL 19 0000000000 0000000000 0000000000 0000000000
 HTVAL 20 0000000000 0000000000 0000000000 0000000000
 HTVAL 21 0000000000 0000000000 0000000000 0000000000
 HTVAL 22 0000000000 0000000000 0000000000 0000000000
 HTVAL 23 0000000000 0000000000 0000000000 0000000000
 HTVAL 24 0000000000 0000000000 0000000000 0000000000
 HTVAL 25 0000000000 0000000000 0000000000 0000000000
 HTVAL 26 0000000000 0000000000 0000000000 0000000000
 HTVAL 27 0000000000 0000000000 0000000000 0000000000
 HTVAL 28 0000000000 0000000000 0000000000 0000000000
 HTVAL 29 0000000000 0000000000 0000000000 0000000000
 HTVAL 30 0000000000 0000000000 0000000000 0000000000
 HTVAL 31 0000000000 0000000000 0000000000 0000000000
```

APPENDIX IV.

Example of Standard Output File

The Standard Output File is the primary output from Program TGPS. It is intended to serve two purposes. The first purpose is to transfer the projected tree lists from TGPS to TABL, the summary program. For users who will always apply Program TABL and never do any further processing, the contents and structure of this file are irrelevant. The second purpose of the Standard Output File is to provide a file of projected tree lists that is easy to use with any user-written summary routine or standard statistical package. All information available about the plot is included so that summaries can be made for requirements not covered by Program TABL.

This appendix presents a portion of the file from which the example tables used in this Guide were produced. The first five lines hold information that remains constant for a plot throughout the projection period.

The first line shows property name, plot name, area expansion factor for the plot, site index, number of years in the projection, type of mortality, number of cycles for the plot, date and time of the run that created this file. The NP array on the second line holds run parameters for the plot. The SITE array on the third and fourth lines holds site index for each of the 31 FREP species groups and the IYR array on the fifth line shows the year associated with each growth cycle.

The sixth and seventh lines present plot information that changes for each cycle. On the sixth line property and plot names are repeated and current year, cycle number, and cover type are shown. The IP array on the seventh line holds other plot information. The next lines hold the actual tree list. The information presented for tree number 1 is USDA Forest Service species code 105 for jack pine, d.b.h. is 3.0, crown ratio is 3.47, height is 0 (not computed), crown ratio difference is 0, current year's growth is 0 (for initial cycle), initial observed d.b.h. is 3.0, tree expansion factor is 20.0, basal area of this tree is 0.98, tree status is 1 (live), tree number is repeated, FREP species group is 1, and tree class is 10. Tree list entries are shown for the 45 sample trees on this plot. This completes the tree list for the initial conditions (ICYCLE = 0). The remaining information is the first part of the tree list for cycle 1 (ICYCLE = 1).

A more detailed discussion of the Standard Output File can be found in the Programmer's Guide.

```
PROP=FREP FOREST      PLOT=317 A    APRLOC=     1.0 SITE=  60 KYRS=  31 KIND= 1 MEA= 4   80/07/31.   16.33.57.
NP=   2  10   3   1   0        0   0        0   2   0
SITE=  60.0  57.8  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0
       60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0  60.0
 IYR=  1980  1990  2000  2010
PROP=FREP FOREST      PLOT=317 A    KYR= 1980 ICYCLE=  0 KTYPE=  1 MGTYR=   0 ACT=                      NST=   45
IP=   45    0    0    0   89    1    0    2   60   30  900    0   20    0    0    0    0 1980    0    0

  1  105. 3.000 3.47  0     0     0  3.00     0     0     0     0     0 20.00     0     0    .98   1   1   1   0   0   0  10
  2  105. 3.300 3.51  0     0     0  3.30     0     0     0     0     0 20.00     0     0   1.19   1   2   1   0   0   0  10
  3  105. 3.500 3.54  0     0     0  3.50     0     0     0     0     0 20.00     0     0   1.34   1   3   1   0   0   0  10
  4  105. 4.300 3.65  0     0     0  4.30     0     0     0     0     0 20.00     0     0   2.02   1   4   1   0   0   0  10
  5  105. 4.300 3.65  0     0     0  4.30     0     0     0     0     0 20.00     0     0   2.02   1   5   1   0   0   0  10
  6  105. 4.000 3.61  0     0     0  4.00     0     0     0     0     0 20.00     0     0   1.75   1   6   1   0   0   0  10
  7  105. 4.100 3.62  0     0     0  4.10     0     0     0     0     0 20.00     0     0   1.83   1   7   1   0   0   0  10
  8  105. 4.400 3.66  0     0     0  4.40     0     0     0     0     0 20.00     0     0   2.11   1   8   1   0   0   0  10
  9  105. 4.700 3.70  0     0     0  4.70     0     0     0     0     0 20.00     0     0   2.41   1   9   1   0   0   0  10
 10  105. 4.800 3.71  0     0     0  4.80     0     0     0     0     0 20.00     0     0   2.51   1  10   1   0   0   0  10
 11  105. 4.500 3.67  0     0     0  4.50     0     0     0     0     0 20.00     0     0   2.21   1  11   1   0   0   0  10
 12  105. 4.700 3.70  0     0     0  4.70     0     0     0     0     0 20.00     0     0   2.41   1  12   1   0   0   0  10
 13  105. 4.600 3.69  0     0     0  4.60     0     0     0     0     0 20.00     0     0   2.31   1  13   1   0   0   0  10
 14  105. 5.300 3.78  0     0     0  5.30     0     0     0     0     0 20.00     0     0   3.06   1  14   1   0   0   0  10
 15  105. 5.400 3.79  0     0     0  5.40     0     0     0     0     0 20.00     0     0   3.18   1  15   1   0   0   0  10
 16  105. 5.200 3.76  0     0     0  5.20     0     0     0     0     0 20.00     0     0   2.95   1  16   1   0   0   0  10
 17  105. 5.000 3.74  0     0     0  5.00     0     0     0     0     0 20.00     0     0   2.73   1  17   1   0   0   0  10
 18  105. 5.400 3.79  0     0     0  5.40     0     0     0     0     0 20.00     0     0   3.18   1  18   1   0   0   0  10
 19  105. 5.000 3.74  0     0     0  5.00     0     0     0     0     0 20.00     0     0   2.73   1  19   1   0   0   0  10
 20  105. 5.700 3.83  0     0     0  5.70     0     0     0     0     0 20.00     0     0   3.54   1  20   1   0   0   0  10
 21  105. 5.800 3.84  0     0     0  5.80     0     0     0     0     0 20.00     0     0   3.67   1  21   1   0   0   0  10
 22  105. 6.000 3.86  0     0     0  6.00     0     0     0     0     0 20.00     0     0   3.93   1  22   1   0   0   0  10
 23  105. 5.900 3.85  0     0     0  5.90     0     0     0     0     0 20.00     0     0   3.80   1  23   1   0   0   0  10
 24  105. 6.600 3.93  0     0     0  6.60     0     0     0     0     0 20.00     0     0   4.75   1  24   1   0   0   0  10
 25  105. 6.300 3.90  0     0     0  6.30     0     0     0     0     0 20.00     0     0   4.33   1  25   1   0   0   0  10
 26  741. 1.100 3.36  0     0     0  1.10     0     0     0     0     0 20.00     0     0    .13   1  26  25   0   0   0  10
 27  741. 1.300 3.37  0     0     0  1.30     0     0     0     0     0 20.00     0     0    .18   1  27  25   0   0   0  10
 28  741. 1.300 3.37  0     0     0  1.30     0     0     0     0     0 20.00     0     0    .18   1  28  25   0   0   0  10
 29  741. 2.200 3.43  0     0     0  2.20     0     0     0     0     0 20.00     0     0    .53   1  29  25   0   0   0  10
 30  741. 2.700 3.46  0     0     0  2.70     0     0     0     0     0 20.00     0     0    .80   1  30  25   0   0   0  10
 31  741. 2.600 3.45  0     0     0  2.60     0     0     0     0     0 20.00     0     0    .74   1  31  25   0   0   0  10
 32  741. 2.600 3.45  0     0     0  2.60     0     0     0     0     0 20.00     0     0    .74   1  32  25   0   0   0  10
 33  741. 2.500 3.45  0     0     0  2.50     0     0     0     0     0 20.00     0     0    .68   1  33  25   0   0   0  10
 34  741. 2.800 3.46  0     0     0  2.80     0     0     0     0     0 20.00     0     0    .86   1  34  25   0   0   0  10
 35  741. 3.400 3.50  0     0     0  3.40     0     0     0     0     0 20.00     0     0   1.26   1  35  25   0   0   0  10
 36  741. 3.300 3.50  0     0     0  3.30     0     0     0     0     0 20.00     0     0   1.19   1  36  25   0   0   0  10
 37  741. 3.400 3.50  0     0     0  3.40     0     0     0     0     0 20.00     0     0   1.26   1  37  25   0   0   0  10
 38  741. 3.100 3.48  0     0     0  3.10     0     0     0     0     0 20.00     0     0   1.05   1  38  25   0   0   0  10
 39  741. 3.200 3.49  0     0     0  3.20     0     0     0     0     0 20.00     0     0   1.12   1  39  25   0   0   0  10
 40  741. 3.800 3.53  0     0     0  3.80     0     0     0     0     0 20.00     0     0   1.58   1  40  25   0   0   0  10
 41  741. 4.000 3.54  0     0     0  4.00     0     0     0     0     0 20.00     0     0   1.75   1  41  25   0   0   0  10
 42  741. 3.600 3.52  0     0     0  3.60     0     0     0     0     0 20.00     0     0   1.41   1  42  25   0   0   0  10
 43  741. 4.300 3.56  0     0     0  4.30     0     0     0     0     0 20.00     0     0   2.02   1  43  25   0   0   0  10
 44  741. 4.500 3.57  0     0     0  4.50     0     0     0     0     0 20.00     0     0   2.21   1  44  25   0   0   0  10
 45  741. 5.100 3.61  0     0     0  5.10     0     0     0     0     0 20.00     0     0   2.84   1  45  25   0   0   0  10

PROP=FREP FOREST      PLOT=317 A    KYR= 1990 ICYCLE=  1 KTYPE=  1 MGTYR=1985 ACT=DO NOTHING           NST=   45
IP=   45    0    1    0   89    1    0    2   60   30  900  700   20    0    0    0    0 1980    0    0

  1  105. 3.517 3.2322.       0 .0404  3.00     0     0     0     0     0 20.00     0 1990.   1.35   3   1   1   0   0   0  10
  2  105. 3.903 3.2822.       0 .0476  3.30     0     0     0     0     0 20.00     0 1990.   1.66   3   2   1   0   0   0  10
  3  105. 4.163 3.2722.       0 .0528  3.50     0     0     0     0     0 20.00     0     0   1.89   1   3   1   0   0   0  10
```

APPENDIX V.

Legend for Summary Tables

THREE TYPES OF TABLES ARE PRODUCED BY "STEMS":

1. PLOT SUMMARY TABLES,
   TWO VERSIONS OF PLOT SUMMARIES ARE PRODUCED:
   A. PLOT SUMMARY TABLE FOR ONE CYCLE.
   B. PLOT SUMMARY TABLE FOR TOTAL PROJECTION PERIOD.
2. RUN SUMMARY TABLE FOR ALL PLOTS IN THE RUN FOR EACH CYCLE AND FOR ALL CYCLES IN THE RUN.
3. COVER TYPE SUMMARY TABLE FOR ALL PLOTS IN THE RUN FOR EACH CYCLE AND FOR ALL CYCLES.

DEFINITIONS OF TERMS USED IN TABLES BY ORDER OF THEIR APPEARANCE:

PLOT SUMMARY TABLE:

DATE -
THE FIRST LINE HOLDS THE PROGRAM NAME ("STEMS") AND THE DATE THAT THESE TREE LISTS WERE PROJECTED. NOTE THAT THIS MAY NOT BE THE SAME DATE THAT THE TABLES WERE PRINTED.

TITLE -
THE NEXT LINE IN EACH TABLE IS THE TITLE SET IN PROGRAM TGPS. NEXT IS THE TITLE SET IN THIS SUMMARY RUN. EACH TITLE IS NO MORE THAN 80 CHARACTERS LONG.

PROPERTY -
AN ARBITRARY PROPERTY IDENTIFIER. MAY CONSIST OF UP TO 16 NUMBERS OR LETTERS. USUALLY SET FROM A TREE LIST HEADER CARD.

PLOT -
AN ARBITRARY PLOT IDENTIFIER. MAY CONSIST OF UP TO 8 NUMBERS OR LETTERS. USUALLY SET FROM A TREE LIST HEADER CARD.

TABLE TYPE -
TABLE TYPE, GROWTH CYCLE NUMBER AND TOTAL NUMBER OF CYCLES.

COVER TYPE -
CURRENT PLOT COVER TYPE. SET IN SUBROUTINE COVTYP ACCORDING TO AMOUNT OF BASAL AREA PRESENT IN EACH SPECIES GROUP.

SITE INDEX -
NUMERIC PLOT SITE INDEX.

PLOT AREA EXPANSION FACTOR -
NUMBER OF ACRES REPRESENTED BY THIS PLOT.

INITIAL YEAR -
BEGINNING YEAR OF THE CYCLE.

CURRENT YEAR -
THE TABLE SUMMARIZES THE CONDITION OF THIS PLOT IN THIS YEAR.

INITIAL AGE -
STAND AGE IN YEARS AT INITIAL YEAR.

CURRENT AGE -
STAND AGE AT CURRENT YEAR.

UNITS -
VOLUMES ARE PRESENTED IN THESE UNITS.

TYPE OF MORTALITY -
EITHER DETERMINISTIC OR PROBABILISTIC.

AVERAGE STAND DIAMETER -
ARITHMETIC AVERAGE OF DIAMETERS OF ALL LIVE TREES ON THE PLOT AT THE CURRENT YEAR.

INGROWTH DIAMETER -
TREES THAT CROSS THIS DIAMETER LIMIT ARE INCLUDED IN THE INGROWTH COLUMN OF THE TREES AND BASAL AREA TABLE.

MEAN ANNUAL INCREMENT -
MEAN ANNUAL INCREMENT (MAI) IS THE SUM OF CURRENT VOLUME AND VOLUME OF ALL REMOVALS THAT OCCURED SINCE THE PROJECTION OF THE PLOT BEGAN, DIVIDED BY THE CURRENT STAND AGE. NOTE THAT IF ANY CUTTING WAS DONE BEFORE PROJECTION BEGAN, THIS VALUE WILL NOT REFLECT THE TRUE MAI.

MANAGEMENT ACTION -
TYPE OF TREATMENT PERFORMED DURING THIS CYCLE.

YEAR OF INITIAL REGENERATION -
PRINTED ONLY IF INITIAL REGENERATION HAS OCCURRED. THIS IS THE YEAR THE PREVIOUS STAND WAS REMOVED, NOT THE YEAR THAT NEW TREES SHOWED UP ON THE TREE LIST.

SPECIES GROUP (FOR OUTPUT SUMMARY) -
GENERALLY A SPECIES GROUP CONTAINS ONLY ONE SPECIES. HOWEVER, IF SEVERAL SPECIES HAVE SIMILAR CHARACTERISTICS OR IF DATA ARE LACKING, SPECIES MAY BE GROUPED. FOR EXAMPLE, AMERICAN ELM, SLIPPERY ELM AND ROCK ELM ARE ALL GROUPED AS ELM. THIS GROUPING IS DONE BY THE USER BEFORE RUNNING "STEMS" AND FORMS THE BASIS FOR AN INDEX TO ACCESS THE VOLUME, MORTALITY, AND OTHER COEFFICIENTS USED IN THE PROJECTION EQUATIONS AND MARKING RULES.

DIAMETER CLASS -
CLASS LIMITS ARE SET BY THE USER AND ARE FOR OUTPUT CLASSIFICATION ONLY. THE SMALLEST CLASS IS BOUNDED BELOW BY ZERO AND THE LARGEST IS OPEN ABOVE.

INITIAL TREES -
NUMBER OF LIVE TREES PER ACRE AT THE BEGINNING OF THIS PERIOD.

INITIAL BA -
BASAL AREA PER ACRE OF LIVE TREES IN SQUARE FEET AT THE BEGINNING OF THIS PERIOD.

NON-ING TREES -
NUMBER OF LIVE TREES PER ACRE THAT DID NOT CROSS A USER-SET INGROWTH DIAMETER LIMIT DURING THE CYCLE. (NON-INGROWTH TREES).

NON-ING BA -
BASAL AREA PER ACRE OF NON-INGROWTH TREES IN SQUARE FEET.

INGROWTH TREES -
NUMBER OF LIVE TREES PER ACRE THAT CROSSED THE USER-SET INGROWTH DIAMETER LIMIT (DBHINT) DURING THIS CYCLE.

INGROWTH BA -
BASAL AREA PER ACRE OF INGROWTH TREES IN SQUARE FEET AT THE CURRENT TIME.

MORTALITY TREES -
NUMBER OF TREES PER ACRE THAT WERE ALIVE AT THE BEGINNING OF THIS PERIOD BUT ARE NOW DEAD. (CLASSIFIED BY DIAMETER AT TIME OF DEATH)

MORTALITY BA -
BASAL AREA OF MORTALITY TREES IN SQUARE FEET AT THE TIME OF DEATH.

REMOVALS TREES -
NUMBER OF TREES PER ACRE THAT WERE CUT DURING THIS PERIOD. (CLASSIFIED BY DIAMETER AT TIME OF CUT)

REMOVALS BA -
BASAL AREA PER ACRE OF REMOVALS IN SQUARE FEET AT TIME OF CUT.

CURRENT TREES -
NUMBER OF LIVE TREES PER ACRE AT THE CURRENT YEAR. NOTE THAT THE TOTAL BY SPECIES GROUP EQUALS (INITIAL TREES) + (REGENERATION TREES) - (MORTALITY TREES) - (REMOVALS TREES). EQUALITY MAY NOT APPLY TO A SINGLE DIAMETER CLASS BECAUSE TREES TEND TO MOVE UP INTO HIGHER DIAMETER CLASSES.

CURRENT BA -
BASAL AREA PER ACRE OF LIVE TREES IN SQUARE FEET.

GROWTH (BA) -
NET BASAL AREA GROWTH FOR THIS PERIOD: (CURRENT BA) + (REMOVALS BA) - (INITIAL BA).

INITIAL VOLUME (INVENTORY OF THE STAND) -
CUBIC FOOT VOLUME PER ACRE OF INITIAL TREES AT THE BEGINNING OF THIS PERIOD. INCLUDES ALL LIVE TREES THAT ARE LARGE ENOUGH TO HAVE VOLUME.

GROWTH ON NON-ING -
CUBIC FOOT VOLUME GROWTH ON NON-ING TREES FOR THIS PERIOD. NON-INGROWTH TREES FOR VOLUME COMPUTATIONS ARE TREES THAT DID NOT CROSS THE USER-SET INGROWTH LIMIT (DBHINV).

INGROWTH AND GROWTH ON INGROWTH -
PRESENT CUBIC FOOT VOLUME OF INGROWTH TREES. INGROWTH VOLUME IS THE VOLUME OF A TREE AT THE USER-SET INGROWTH LIMIT (DBHINV). THE VOLUME INCLUDED BETWEEN CURRENT DIAMETER AND DBHINV IS CONSIDERED GROWTH ON INGROWTH.

OTHER GROWTH -
VOLUME OF GROWTH ON MORTALITY PLUS GROWTH ON REMOVALS. GROWTH ON MORTALITY = VOLUME OF THE TREE AT TIME OF DEATH MINUS THE TREE VOLUME AT THE BEGINNING OF THIS PERIOD.

GROWTH ON REMOVALS = VOLUME OF THE TREE AT TIME OF CUT MINUS THE TREE VOLUME AT THE BEGINNING OF THIS PERIOD.

GROSS GROWTH -
SUM OF ALL VOLUME GROWTH ON PLOT FOR THIS PERIOD. COMPUTED AS: (GROWTH ON NON-ING) + (INGROWTH) + (GROWTH ON INGROWTH) + (GROWTH ON MORTALITY) + (GROWTH ON REMOVALS).

MORTALITY -
VOLUME OF ALL MORTALITY TREES AT THE TIME OF DEATH.

NET GROWTH -
COMPUTED AS: (GROSS GROWTH) - (MORTALITY).

REMOVALS -
VOLUME OF ALL TREES CUT DURING THIS PERIOD.

NET INCREASE IN INVENTORY -
TOTAL CHANGE IN INVENTORY OF THE STAND. COMPUTED AS: (NET GROWTH) - (REMOVALS).

CURRENT VOLUME -

VOLUME OF ALL LIVE TREES REMAINING IN THE STAND AFTER GROWTH, MORTALITY, AND REMOVALS FOR THIS CYCLE AND ALL PREVIOUS CYCLES HAVE BEEN APPLIED TO THE INITIAL TREE LIST. THE TOTAL CURRENT VOLUME FOR EACH SPECIES AND FOR THE PLOT EQUALS: (INITIAL VOLUME) + (NET INCREASE IN INVENTORY). HOWEVER THIS RELATION MAY NOT HOLD FOR DIAMETER CLASS TOTALS BECAUSE TREES GROW AND CHANGE DIAMETER CLASS.

RUN SUMMARY TABLE:

RUN SUMMARY TABLES PRESENT THE CONDITION OF ALL PLOTS IN THE RUN AT THE FINAL YEAR OF PROJECTION. THE MEANINGS OF ALL THE COLUMNS ARE THE SAME AS FOR THE PLOT SUMMARY TABLES EXCEPT THAT THE RUN SUMMARY PRESENTS THE TOTAL VALUES FOR EVERY TREE ON EVERY PLOT EXPANDED BY PLOT AREA EXPANSION FACTOR. THESE ARE NOT AVERAGES AND ARE NOT REDUCED TO A PER ACRE BASIS.

COVER TYPE SUMMARY TABLES:

COVER TYPE SUMMARY TABLES PRESENT COVER TYPE SUMMARIES AT THE FINAL YEAR OF PROJECTION. EACH TABLE ENTRY IS THE AVERAGE FOR THAT COVER TYPE WEIGHTED BY THE AREA IN THAT COVER TYPE.

COVER TYPE -

PLOT COVER TYPE SET IN SUBROUTINE COVTYP ACCORDING TO THE AMOUNT OF BASAL AREA PRESENT IN EACH SPECIES. THIS IS THE COVER TYPE OF THE PLOT AT THE FINAL YEAR OF PROJECTION. NOTE THAT IF A PLOT ENTERS "STEMS" AS NORTHERN HARDWOODS AND THROUGH MORTALITY OR MANAGEMENT BECOMES OAK-HICKORY IT WILL NOT CONTRIBUTE TO THE NORTHERN HARDWOOD LINE IN THE COVER TYPE SUMMARY TABLE.

AREA -

TOTAL AREA REPRESENTED BY THE COVER TYPE (NOT AN AVERAGE).

ALL OTHER COLUMNS ARE THE SAME AS FOR THE PLOT SUMMARY TABLES EXCEPT THAT THE COVER TYPE SUMMARY PRESENTS THE AVERAGE PER ACRE VALUES FOR EACH COVER TYPE FOR ALL PLOTS IN THE RUN.

APPENDIX VI.

Procedure for accessing STEMS at the Fort Collins Computer Center (FCCC)

The version of STEMS described in this Guide resides at FCCC. This appendix presents instructions for National Forest System personnel who wish to use the program at FCCC. Three run streams are available for use:

1. FREP-R9*STEMS.PROJ-SUM-FXX	which runs both the projection program (TGPS) and the summary program (TABL);
2. FREP-R9*STEMS.PROJ-FXX	which runs the projection program only;
3. FREP-R9*STEMS.SUM-FXX	which runs the summary program only.

The run stream for both the projection and summary programs is as follows:

```
 1:@MSG,N . RUNSTREAM FOR PROJECTION AND SUMMARY
 2:@DELETE,C STEMOUTXX.
 3:@ASG,UP STEMOUTXX.,F40///512
 4:@ASG, A TREELIST.                . INITIAL TREE LIST
 5:@TASG,T 20,512                   . TEMPORARY FILE
 6:@TASG,T 21,512                   . TEMPORARY FILE
 8:@BRKPT PRINT$/STEMOUTXX
 9:@USER*JOB.IDENT FRED-STEMS,FOREST$XX
10:@XQT FREP-R9*STEMS.TGPS          . TGPS PROGRAM.
11:@ADD FREP-R9*STEMS.TGPSRUNFXX    . TGPS RUN OPTIONS
12:@ADD FREP-R9*STEMS.VOLSLS        . BIOMASS AND VOLUME COEFFICIENTS
13:@ADD FREP-R9*STEMS.SYSINPFXX     . SYSTEM PARAMETERS AND SPECIFICATIONS
14:@ADD,E TREELIST
15:@XQT FREP-R9*STEMS.TABL          . TABL PROGRAM
16:@ADD FREP-R9*STEMS.TABLRUNFXX    . TABL RUN OPTIONS
17:@ADD FREP-R9*STEMS.VOLSLS        . BIOMASS AND VOLUME COEFFICIENTS
18:@ADD FREP-R9*STEMS.LEGEND        . LEGEND FOR TABLE HEADINGS
19:@BRKPT PRINT$
20:@FREE STEMOUTXX
21:@SYM STEMOUTXX.,,FCR072
```

To create a copy of FREP-R9*STEMS.PROG-SUM-FXX specific to your own National Forest (using OTTAWA-07 as an example), type:

```
@ED,I FREP-R9*STEMS.PROJ-SUM-F07
INPUT      (Computer response)
(CR)       (Carriage return)
EDIT       (Computer response)
ADD  FREP-R9*STEMS.PROJ-SUM-FXX    (Add the entire prior run stream)
EOF  FOUND (Computer response)
C  /XX/07/ ALL  (This will change all occurrences of XX to 07)

(Change the file name TREELIST in lines 4 and 14 to your tree list file)

EXIT
```

Before executing the program you must prepare several other files:

FREP-R9*STEMS.TGPSRUNFXX
TGPS run options (discussed on p. 2);

FREP-R9*STEMS.VOLSLS
biomass and volume coefficients (discussed on p. 4 and Appendix II);

FREP-R9*STEMS.SYSINPFXX
system parameters and specifications (discussed on p. 5 and Appendix III); and

FREP-R9*STEMS.TABLRUNFXX
TABL run options (discussed on p. 10).

Each file should have the XX changed to your forest code (07 for OTTAWA). To execute the program, type:

```
@ADD FREP-R9*STEMS.PROJ-SUM-F07
```

Your output will be printed at the Regional Office in Milwaukee and mailed to you.

Occasionally, you may need to save the intermediate output (Standard Output File). If so, the projection program should be run separately from the summary program. The run stream for the projection program only is:

```
 1:@MSG,N . RUNSTREAM FOR PROJECTION ONLY
 2:@MSG,N . STANDARD OUTPUT FILE IS PERMANENT
 3:@DELETE,C TGPSOUTFXX.
 4:@ASG,UP TGPSOUTFXX.
 5:@ASG,A TREELIST.
 6:@BRKPT PRINT$/TGPSOUTFXX
 7:@USER*JOB.IDENT FREP-STEMS,FOREST$XX
 8:@XQT FREP-R9*STEMS.TGPS
 9:@ADD FREP-R9*STEMS.TGPSRUNFXX
10:@ADD FREP-R9*STEMS.VOLSLS
11:@ADD FREP-R9*STEMS.SYSINPFXX
12:@ADD,E TREELIST.
13:@BRKPT PRINT$
14:@FREE TGPSOUTFXX.
15:@SYM TGPSOUTFXX.,,FCR072
```

To create your own copy use the same procedure as for FREP-R9*STEMS.PROJ-SUM-FXX except replace that file name with FREP-R9*STEMS.PROJ-FXX.

To execute the projection program only, type:

```
@ASG,UP FILEONE.,F40///512
@ASG,UP FILETWO.,F40///512
@USE  21,FILEONE.
@USE  22,FILETWO.
@ADD  FREP-R9*STEMS.PROJ-F07
```

FILEONE and FILETWO are any temporary file names and 07 is again used as an example.

Next, the summary program should be run. Its run stream is:

```
 1:@MSG,N . RUNSTREAM FOR SUMMARY ONLY
 2:@DELETE,C TABLOUTXX.
 3:@ASG,UP TABLOUTXX.
 4:@TASG,T 20,512
 5:@BRKPT PRINT$/TABLOUTXX
 6:@USER*JOB.IDENT FREP-STEMS.FOREST$XX
 7:@XQT FREP-R9*STEMS.TABL
 8:@ADD FREP-R9*STEMS.TABLRUNFXX
 9:@ADD FREP-R9*STEMS.VOLSLS
10:@ADD FREP-R9*STEMS.LEGEND
11:@BRKPT PRINT$
12:@FREE TABLOUTXX
13:@SYM TABLOUTXX.,,FCR072
```

Create your own copy with the previous procedure except replace the file name with FREP-R9*STEMS.SUM-FXX.

To execute the summary program, type:

```
@ASG,A  FILEONE.
@ASG,A  FILETWO.
@USE  21,FILEONE.
@USE  22,FILETWO.
@ADD  FREP-R9*STEMS.SUM-07
```

Your output will be printed at the Regional Office in Milwaukee and mailed to you.

If you wish to keep the Standard Output File for more than 6 days, you must use the @SAVE command for both FILEONE and FILETWO.

The run streams and procedures presented here provide only a simple way to use the STEMS system. If you require more detailed analyses, contact the Timber Management Group in the Milwaukee Regional Office.

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Belcher, David M.

1981. User's guide to STEMS (Stand and Tree Evaluation and Modeling System). U.S. Department of Agriculture Forest Service, General Technical Report NC-70, 49 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Presents the structure of STEMS, a computer program for projecting the growth of individual trees within the Lake States Region, and discusses its input, processing, major subsystems, and output. Includes an example projection.

KEY WORDS: forest growth, simulation, mixed species, distance independent, individual tree, FORTRAN.

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